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Development of Bottom Oil Recovery Systems - Final Project Report

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16. Abstract (MAXIMUM 200 WORDS)

Facilities or vessels which store or transport heavy and/or sinking oils in U.S. waters must identify response organizations and strategies for responding to spills of these products, including identifying methods for assessing, containing, recovering oil and decanting oil and water from subsurface environments. The U.S. Coast Guard (USCG) has acknowledged current technologies are not adequate to accomplish these objectives. The objective of this project was to develop and test viable designs for systems which can detect and recover oil from subsurface environments.

The USCG Research and Development Center (RDC) first addressed detection issues and determined that laser fluorometry and multi-beam sonar were the best practice. RDC then developed specifications and awarded three contracts to design a complete detection and recovery system to Alion Science & Technology Corporation, Marine Pollution Control, and the Oil Stop Division of American Pollution Control. In 2011, these three companies were awarded options to build prototypes for testing. This report describes the designs of the three systems and results from prototype testing at the Ohmsett test facility in Leonardo, New Jersey. It also discusses the path forward for submerged oil detection, recovery, and decanting.

In Section B, this report provides guidance for Federal On Scene Coordinators (FOSC) on the unique issues that need to be addressed before attempting detection and recovery of any oil sitting on the bottom. Based on this project, guidance is provided for assessment of the environment, selection of recovery techniques and decanting and a list of case histories.

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EXECUTIVE SUMMARY

The Oil Pollution Act of 1990 (OPA 90) requires facilities or vessels which store or transport Group V oils (heavy oils, sinking oils) in U.S. waters to identify response organizations and strategies for responding to spills of these products, including identifying methods for assessing, containing and recovering oil from subsurface environments. Current methods are inadequate to find and recover submerged oil, with responders having to reinvent the techniques on each occasion.

The complexity of submerged oil response is exacerbated by the variances in conditions experienced in a sub-surface marine environment. As illustrated in the comparison of riverine (*M/T Athos I*), open-ocean (*T/V Prestige*), and oil-field deep ocean drilling (Deepwater Horizon) related spills, the problems associated with tracking, containing, and recovering oil will vary widely. In addition, environmental factors such as water current, temperature and access to spills create situations that challenge even the best equipped and most experienced responders. Of all the strategies in traditional oil spill response that increase success, the timing of getting the appropriate equipment on scene will be a major challenge in maximizing response efficiency and effectiveness. Submerged oil tracking, mapping and recovery is a largely unexplored area of spill response and one with many facets to be considered. The Coast Guard Research and Development Center (RDC) embarked on a multi-year project to develop a complete approach for recovery of spills of submerged oils. Work indentified below represents innovative and practical development to help solve the many challenges ahead.

Three companies spent one year in designing separate systems to identify and recover oil that has settled on the bottom and then built prototype systems. The three systems were taken to Ohmsett, the Oil Spill Response Research and Renewable Energy Test Facility for evaluation. The three systems were:

- Alion developed a lightweight system using Remotely Operated Vehicles (ROVs). The ROVs may need more power and the pump intake nozzle may need to be smaller.
- Marine Pollution Control (MPC) designed a system based on a manned submersible. It can go deeper and stay longer than a diver, but may have high costs; due to the support needed for the submersible. The manned submersible was not evaluated at Ohmsett due to the size being larger than the facility could handle. This system was also not field tested; due to the high cost of the manned submersible.
- The Oil Stop Bottom Oil Recovery System (OSBORS) Group designed a recovery system based on dredging technology. It could handle harsh wind/wave conditions but has significant logistical requirements, due to its size and weight; and potential environmental impacts from the crawler's movement on the subsurface floor. The crawler was too large to evaluate at Ohmsett; therefore, only the oil recovery nozzle was tested

The systems provided different concepts for replacing the need for divers to work with pumps on the seafloor. They have unique capabilities but need more work to decrease the amount of water/silt collected. Field tests were conducted in 2012 for the Alion and OSBORS systems to evaluate aspects of the systems that were not addressed in the Ohmsett tests.

Through this project, the USCG has taken a step forward in heavy oil detection and recovery capabilities. However, each spill will be different and the Federal On Scene Coordinator (FOSC) will need to determine what techniques to use. This report includes guidelines in Part B for FOSCs responding to spills of sunken

oil. Specific issues that need to be addressed are provided for oil behavior, detection and tracking, recovery including net environmental benefit analysis and decanting, and a list of incidents and case studies.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACHP	Advisory Council on Historic Preservation
AMPOL	American Pollution Control Group
API	American Petroleum Institute
ARPA	Archeological Resource Protection Act
BAA	Broad Agency Announcement
CONOPS	Concept of Operations
CRRC	Coastal Research and Response Center
cSt	Centistokes
CZMA	Coastal Zone Management Act
DEP	Department of Environmental Protection
DNR	Department of Natural Resources
EFH	Essential Fish Habitat
EIC	EIC Laboratories, Inc.
EPA	Environmental Protection Agency
ESA	Endangered Species Act
ESI	Environmental Sensitivity Index
FOSC	Federal On Scene Coordinator
FP	Fluorescence polarization
ft	Foot or feet
GPS	Global Positioning System
HFO	Heavy fuel oil
IFO	Intermediate fuel oil
IMO	International Maritime Organization
km^2	Square kilometers
kts	Knots
m/s	Meter(s) per second
M/T	Motor tanker
M/V	Motor vessel
m	Meter or meters
m^2	Square meters
m^3	Cubic meters
MBTA	Migratory Bird Treaty Act
MMPA	Marine Mammal Protection Act
MPC	Marine Pollution Control
NEBA	Net Environmental Benefit Analysis
NEPA	National Environmental Policy Act

NHPA	National Historic Preservation Act
NMFS	National Marine Fisheries Service
No.	Number
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
OPA 90	Oil Pollution Act of 1990
OSBORS	Oil Stop Bottom Oil Recovery System
RDC	USCG Research and Development Center
RFI	Request for Information
ROV	Remotely Operated Vehicle
SAT	Science Advisory Team
SSC	Scientific Support Coordinator
Sea Horse	Seagoing Adaptable Heavy Oil Recovery System
SHPO	State Historic Preservation Officer
T/B	Tanker barge
T/V	Tanker vessel
TMT	Tornado Motion Technologies
U.S.	United States
UC	Unified Command
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
V-SORS	Vessel-Submerged Oil Recovery System
VOC	Volatile organic compound
VOO	Vessel of opportunity
yd^2	Square yards

PART A: SUNKEN OIL RECOVERY PROJECT SUMMARY

1 INTRODUCTION

Even though heavy or sinking oils have historically accounted for a small percentage of the total number of spills, environmental and economic consequences resulting from such spills can escalate due to the persistent nature of mobile and virtually invisible droplets. Heavy oils can sink and destroy shellfish and other marine life populations in addition to causing closure of water intakes at industrial facilities and power plants. Without much notice, they appear on shorelines and in protected marine sanctuaries, carried by the natural movement of the water. The underwater environment poses major problems for spill response, with some of the most obvious reasons being: poor visibility, difficulty in tracking oil spill movement, colder temperatures, inadequate containment methods and technologies, and problems with the equipments' interaction with water.

1.1 Objective

The objective of this project was to develop and test viable designs for systems which can detect and recover oil from subsurface environments up to 200 feet (ft) (61 meters (m)) in depth. Tests were conducted at the Ohmsett test facility (Oil Spill Response Research and Renewable Energy Test Facility) located at the Naval Weapons Station Earl in Leonardo, NJ and in the field. The purpose of the Ohmsett tests was to demonstrate the system's ability to effectively remove highly viscous submerged oil from a variety of simulated bottom conditions, and to receive, handle, and separate the high volume of materials generated from the operation. Field tests were conducted to evaluate aspects of the systems that were not addressed in the Ohmsett tests.

1.2 Background

The Oil Pollution Act of 1990 (OPA 90) requires facilities or vessels which handle, store, or transport oils in U.S. waters to identify response organizations and strategies for responding to spills of these products, including identifying methods for assessing, containing, and recovering oil from subsurface environments. Regardless of whether the oil is on the surface, neutrally buoyant in the water column, or on the bottom, it is difficult to mitigate the threats posed to the health and stability of the environment. Existing systems are inadequate to meet Federal On Scene Coordinator (FOSC) current needs for heavy and sunken oil detection and recovery. The National Academy of Science recognized this issue and developed a report that provided a baseline for responders (National Research Council (NRC), 1999). Since that report, some progress has been made to identify successes and performance gaps (Coastal Research and Response Center (CRRC), 2007, Michel, 2008, and Rymell, 2009). In addition, a guideline for assessment and removal techniques is being developed by the International Maritime Organization (IMO, 2012).

Only a few submerged oil spills have posed significant observable impact to coastal communities and noticeable habitat destruction, which is a potential reason there has been little incentive for industry to develop capabilities to address this type of incident. Responses to recent higher profile submerged oil spills have shown responders had limited capability in detection and recovery and relied on commercial divers to perform the bulk of the work. (Elliott 2008, Elliott 2009) Commercial diving operations have their limits (Elliott 2003). The U.S. Coast Guard (USCG) Research and Development Center (RDC) chose to pursue this effort to increase these capabilities.

Previous to recent USCG efforts, credit is owed to some who have conducted research work into the detection of heavy oil. Laser fluorometers have been shown to have the capability to detect oil spills at night and to detect oil under the water surface, while in-situ fluorometers that detect hydrocarbons in the water column have also been developed. With the innovation of current technology, oil on the bottom has been located visually and with sonar under certain conditions. However, it is anticipated that a combination of sensors may be needed in order to search and confirm the location of sunken oil from most spills.

A traditional method of recovering oil on the bottom of the sea floor has been for a diver to take down a suction hose so that a pump can move the oil to the surface containment vessel. For shallow spills the pump is located on a vessel or pier, and it discharges into some type of holding tank. For deeper oil, submersible pumps are attached to a hose the diver manually inserts into oil, and is helped to its destination by intermediate pumps at the surface. As expected, there are significant limitations with this approach such as lack of sufficient visibility and endurance for the diver, concerns about diver safety, and the large amount of water and sediment collected with the oil. In addition, the methods required for separation of the oil from the other components vary as the oil, sediment, and water temperature change.

2 RDC HEAVY OIL DETECTION PROJECT

The RDC heavy oil project began with a general Request for Information (RFI) in the summer of 2006 asking vendors to provide potential approaches for the detection and recovery of oil on the sea floor. This did not address any oil that is buried or any that is contained in a sunken vessel. A summary of past experiences was provided as part of the RFI. RDC received responses to the RFI from 15 organizations, some of which addressed several topic areas. The five major topics addressed in the responses to the RFI were:

- Detection of Oil in the Water Column,
- Detection of Oil on the Bottom,
- Containment of Suspended Oil/Protection of Water Intakes,
- Containment of Submerged Oil on the Bottom, and
- Recovery of Submerged Oil on the Bottom.

The range of costs in the responses indicated the project would need to proceed in stages. It was determined that if a reliable detection technique could not be developed, then a major research effort should not be mounted for the recovery part of the process. As a result of the information submitted the research effort was divided into two stages, detection and then recovery.

In April of 2007, RDC published a Broad Agency Announcement (BAA) that requested approaches for detection only for oil sitting on the bottom. The objective of this specification was to identify whether or not sensors could provide enough information for decision-makers to determine if the amount of oil present was sufficient to merit recovering. The approach was to divide the BAA process into a proof-of-concept phase (Phase 1) where three to five vendors would be awarded contracts, and then a prototype development phase (Phase 2) where two to three vendors would be awarded contracts. Two sets of performance requirements were listed, one for immediate verification for the concepts and one for the prototypes.

Four detection proof-of-concept devices were evaluated at Ohmsett in November 2007; and two of these were further developed into prototypes for testing in February 2008. Details of these test results are available in a separate report (Hansen et. al., 2009). Based on the results of these tests, the RDC recommended multi-beam sonar and laser fluorometer as best practices for heavy oil detection.

The multi-beam and imaging sonars appear to be the best sensors to conduct wide area detection. Some of the signal return issues, which cause false positive detections for the low grazing angles of common side-scan sonar, are reduced in the systems tested. Most systems should be able to automatically detect large clumps of oil, but the resolution for widely dispersed product is still not complete. Spill responders should ensure that detection equipment has some type of processing software to interpret raw sensor data. This will ensure timely processing and require minimal training for response personnel. The sooner that a system is deployed before the oil breaks up, the better will be the chance that detection will occur.

The laser systems and smaller beam sonars may be better suited as a follow-up to the wide scan areas. These should provide better resolution and should be able to calculate general thickness which could provide some information about the amount of oil. Although the narrow areas covered could introduce resolution issues especially for widely scattered oil, they could be advantageous for guiding recovery efforts.

3 RDC HEAVY OIL RECOVERY PROJECT

3.1 Approach

The RDC developed specifications and released a BAA in June 2009 for a two-phased approach to heavy oil recovery. The Phase 1 System Design was expected to last 10-12 months. The Phase 2 Prototype Development was also expected to last 10-12 months with testing at Ohmsett in 2011.

3.1.1 Phase 1 System Design

Three vendors were awarded contracts to develop designs to meet the specifications:

- Alion Science and Technology Corporation
- Marine Pollution Control (MPC)
- Oil Stop Division of American Pollution Control Group (AMPOL)

The prime vendors teamed with other companies to provide additional expertise. Each vendor addressed the detection, recovery, and processing of the recovered material. Final Phase 1 reports were reviewed in November 2010. The designs are discussed in Section 3.2.

3.1.2 Phase 2 Prototype Development and Testing

Testing of design elements was conducted at Ohmsett in November 2011. Trays were laid on the bottom of the Ohmsett test tank and filled with two types of sand of varying depths and three types of oil with a range of viscosities and layer thicknesses.

3.2 System Design and Ohmsett Testing

The three designs tested at Ohmsett are described below. APPENDIX A gives the summary table of Phase 2 test results.

3.2.1 Alion

Alion developed a heavy oil detection and recovery system called Sea Horse (for Seagoing Adaptable Heavy Oil Recovery System) to meet the requirements identified by the government in the 2009 BAA. Components of the system in all three phases of operation (detection, recovery, and treatment) were chosen to be mobile, flexible, and low cost. The detection phase uses commercially available high-resolution sonar, high accuracy 3-D positioning, and a remotely operated vehicle (ROV). The recovery phase uses ROVs to power an underwater sled, custom software to control the ROVs, and a commercially available pump, generator, and hydraulic power unit. The recovery system consists of two Sea Lion II ROVs, a Lamor GTA 20 pump (capacity of 20 cubic meters/hour (m^3/hr)) with an aluminum nozzle and an aluminum framework with an option to mount a multi-beam sonar. The treatment phase uses a decanting system that can be shipped to the spill site for deployment on a barge, large vessel, or on shore.

The Phase 1 system design was completed in September 2010. The Phase 2 prototype testing occurred at the Ohmsett test facility during November 2011. Phase 2 allowed evaluation of 15 of the 19 requirements identified by the government in the 2009 BAA, at least partially. Figure 1 shows a front view schematic design of Sea Horse and deployment during testing at Ohmsett.

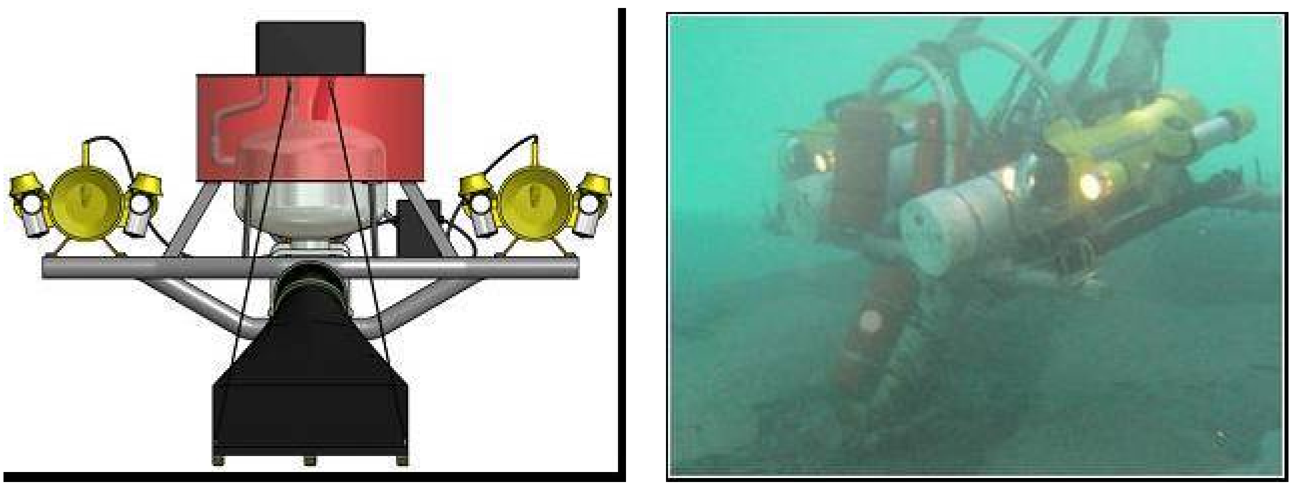


Figure 1. Sea Horse design front view and during testing.

3.2.2 MPC

Marine Pollution Control (MPC) developed a system composed of a manned submersible teamed with a recovery capability and additional sensors including an oil-discriminating sonar and fluorescence polarization (FP) sensor. Figure 2 shows a representation of the general arrangement of the MPC system and Figure 3 shows a conceptual design of the FP sensors on a submersible. Figure 4 shows the submersible with a conceptual oil collection mechanism mounted. The submersible is connected to the surface by a robust, multipurpose marine umbilical system. The main advantages of this approach over divers are the ability of the submersible to stay submerged longer and deeper, as well as the improved visibility the clear sphere provides.

For the Ohmsett tests, MPC provided a test rig (see view from underwater camera in Figure 5) that replicated the dimensions and locations for all of the sensors and recovery nozzle located on the submersible. A camera was also mounted in the approximate position of the eyes of the submersible operator; and the sensors and nozzle were controlled from above the water using this camera.

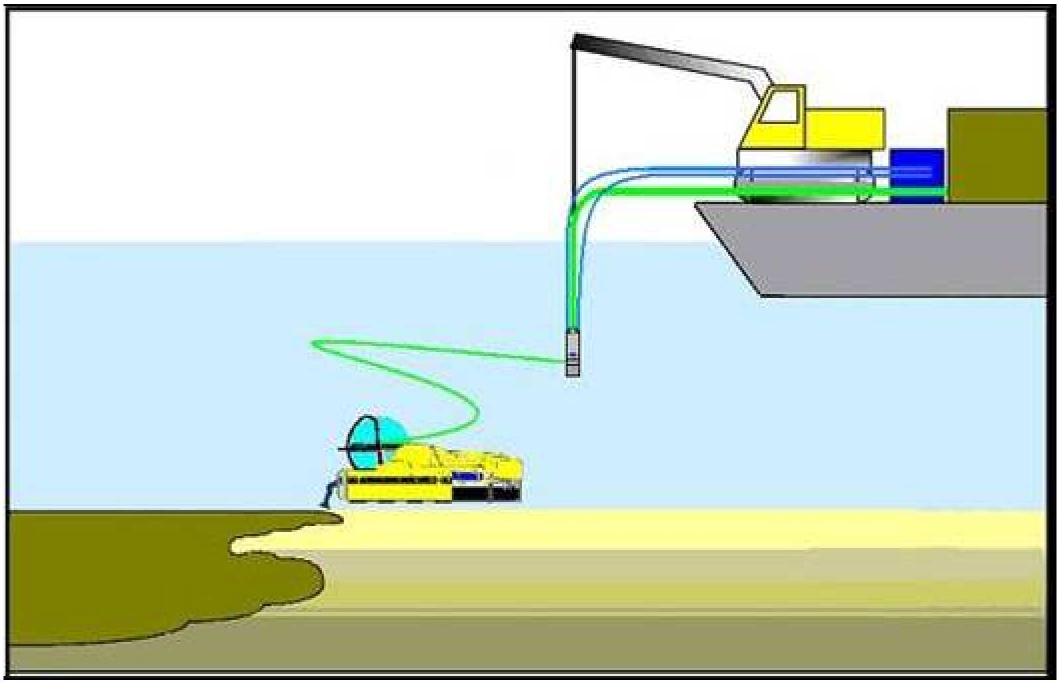


Figure 2. Representation of the general arrangement of the MPC system.

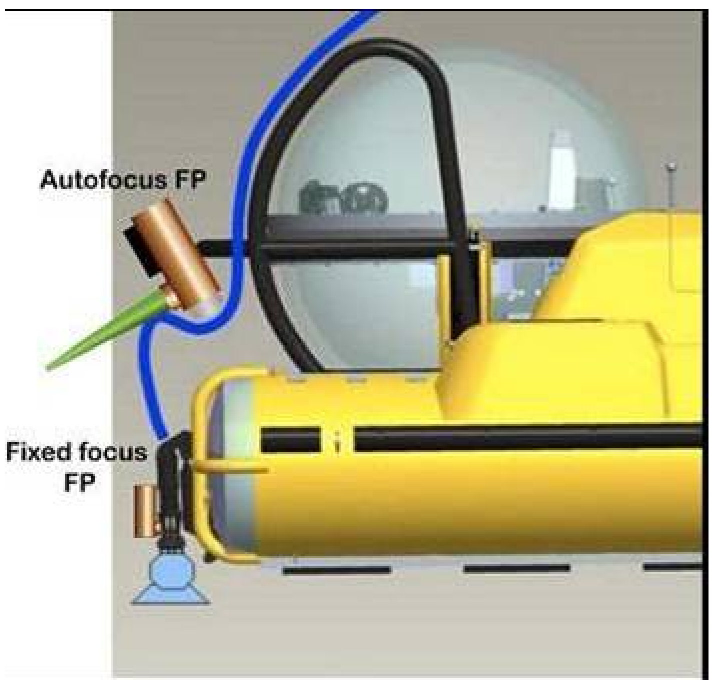


Figure 3. Design concept for FP sensors on a submersible.

Figure 4. Submersible with a conceptual oil collection mechanism mounted.

Figure 5. Underwater view of MPC test rig.

3.2.3 Oil Stop Bottom Oil Recovery System

The Oil Stop Bottom Oil Recovery System (OSBORS) Group designed a specialized package of equipment to remove sunken oil and handle the recovered materials. The primary recovery device is the Sub-dredge, a remote-controlled pumping vehicle designed by Tornado Motion Technologies (TMT) (Figure 6) that weighs about 18,000 pounds. It relies on an external detection system for initial detection, but utilizes underwater cameras during the recovery phase. Figure shows the OSBORS pump mounted on an excavator for the Ohmsett tests. The separation system consists of industry standard elements refined for this application.

Figure 6. OSBORS Sub-dredge.

Figure 7. OSBORS pump mounted on excavator at Ohmsett.

3.3 Field Trials

Field trials were conducted for the Alion and OSBORS systems because much of the capabilities of those systems were not evaluated in the Ohmsett tank. A demonstration of the manned submersible was not conducted primarily due to the high cost of such a demonstration. The vendor did complete at least two field tests on their own that addressed the logistic issues not addressed at Ohmsett such as maneuvering the vehicle with a nozzle and hoses attached and developing emergency jettison procedures.

3.3.1 Alion

Phase 3 testing of the Sea Horse focused on the detection and location capabilities in an ocean environment. Alion conducted tests in the open water environment in Long Island Sound just offshore from Bluff Point, a State Park located in Groton, CT. Figure 8 shows the test target Alion developed to simulate heavy oil.

Alion conducted two demonstrations in water depths greater than 20 ft (6.1 m) and in an area where the sandy/muddy sea floor creates visibility limits of less than 2 ft (0.6 m). In both cases, the sonar was able to locate the targets. In the first demonstration, verifying the identification of the targets with the ROV was not achieved due to equipment and procedure failures. The heading sensor failed in the ROV and the support vessel was not able to keep station with respect to the ROV; thus pulling the ROV’s tether cable. In the second demonstration, verification of the identity of all the targets in the array system with the ROV was achieved using a new Concept of Operations (CONOPS). The new CONOPS involved providing an intermediate anchor point on the ROV tether cable with a buoy to the surface. This permitted the support vessel operator to focus on the surface buoy location and eliminate unnecessary tension on the tether of the ROV. As part of this demonstration, 11 of the 19 original BAA requirements were evaluated, at least partially. These results are included in the summary in Table A-1. The following items were the lessons learned during the two demonstrations.

- Since it is possible for an ROV to fail, it is important to have a backup unit with the same capabilities.
- The heading sensor is essential for effective ROV operation.
- The tending vessel can put too much drag on the ROV for it to work properly; putting an anchor on the umbilical provides a buffer to isolate the vessel motion from the ROV and also has the added benefit of constraining the ROV operations to a limited (known) area.
- The Sea Lion ROVs are easy to use, but difficult to master. An experienced operator will be able to navigate the units with much greater precision and efficiency than a new operator.
- The HYPACK software still has too many crashes, even after upgrading the RAM and video card on the computer.
- There needs to be an intensity calibration curve that can be applied in real-time to the sonar intensity waterfall (this necessity was noticed at Ohmsett as well).
- The real-time streaming interface lost too many packets; the source of this problem needs to be identified and resolved.
- Operations would be improved with real-time live tracking of the ROV integrated onto the HYPACK SURVEY map. This could be done with a pinger system such as TrackLink.

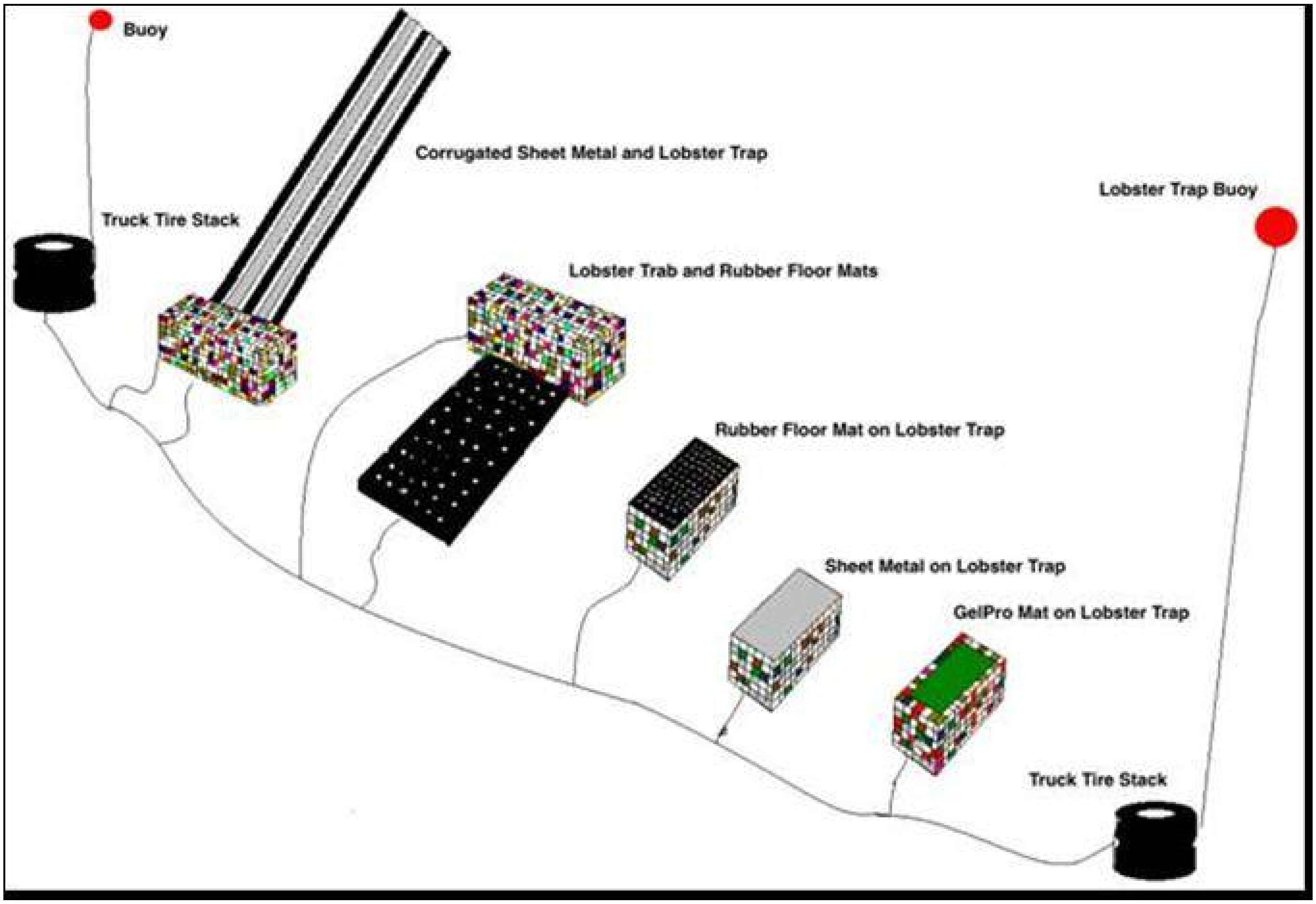


Figure 8. Alion field test target array.

Since the end of the field demonstrations, Alion has redesigned and built a new configuration that uses three ROVs to address the shortfalls identified during the testing (see Figure 9).

Figure 9. Alion redesign using three ROVs.

3.3.2 OSBORS

This final phase of testing the OSBORS was to be an “at sea” trial in at least 25-ft (7.6-m) depth in real situation conditions. The original plan was to the conduct the trials off the coast of California, near the San Diego Harbor area. After a prolonged period of attempting to get approval from all agencies and stakeholders concerned, it became obvious that a timely resolution to the issues for approval would not be forthcoming. The primary issue involved a potential archeological site.

The Oil Stop Division of AMPOL drafted an alternate plan to conduct the trials on an inland, private lake in Texas. The USCG RDC granted an exception to the depth requirement, provided the remote control vehicle would be completely submerged for the designated tasks. AMPOL dispatched a dive team to survey the lake. A suitable area on the lake was surveyed and an area with a water depth of 6-12 ft (1.8-3.6 m) was chosen as the test area. With a favorable report, and following consultation with USCG RDC personnel, the test dates were set for two weeks after the survey.

Bottom oil was simulated using small cotton bags filled with sand and dyed to a black color. An area of approximately 70 x 75 feet (21 x 22.9 meters) was marked with submerged boundary markers. Approximately 3000 “oil bags” were distributed within the boundary. The oil bags were placed to simulate large mats, small clusters and individual “tar balls”.

A newly-designed oil recovery machine, “Ninja” that weighs about 3000 pounds, was launched from the shoreline into the work area (see Figure). Material collection and separation equipment in the form of a phase separator, with 5,000 gallon (18.9 cubic meter) capacity, was placed on shore. Other support equipment and surface support vessels were placed adjacent to the work area.

Summary

Although unexpected mechanical problems with Ninja prevented the team from accomplishing the intended task of removing the simulated oil from the bottom of the lake, many positives resulted from the trials. Foremost, the contract provided the opportunity for the development of the Ninja Mini-Dredge that reduced the size and weight of the original system. The vendors are confident the Ninja, along with the original Sub-Dredge and the Excavator attachment, will be viable tools for use in removing oil from the bottom of water bodies. They intend to organize another field trial in the near future. There may be other commercial opportunities during which they can supplement the operation with “oil recovery” testing.

Figure 10. OSBORS Ninja self-launch.

4 SUMMARY AND CONCLUSION

On many levels, submerged oil response operations represent a new and enhanced capability for the spill response community. Solutions brought to bear on these spills in the past have been successful, but methodologies have been developed on the fly and technologies have been assembled on an ad-hoc basis. While the configurations for the systems discussed in this report are not exactly those expected to be used in the future, these tests have furthered the understanding of heavy/sunken oil response in a number of ways.

The components of any of the systems tested here could be useful in combination if other scenarios are encountered. The development of these systems may not preclude the use of divers in some situations, but may be substituted if the oil is deep (use manned submersible), in a surf zone (use crawler system) or if placing divers into the water is unsafe (use ROV).

4.1 Detection and Mapping

As noted in Section 2 of this report, it should now be possible to detect and map stationary oil on the sea floor and river beds under some conditions using multi-beam sonars and laser fluorometers. There are limitations of the abilities of the sensors, and they still need to be tested in real-world conditions, including depth of water, visibility, and bottom conditions. Recommended research efforts include:

- Determine full capabilities and limits of currently available sensors.
- Improve data processing times and accuracies.
- Develop guidance for use of acoustic and laser sensors.
- Recognize that broad-scale detection and focused recovery detection may require different tools.

Insufficient information is available regarding detection by sonar systems to guide responders as to when this technology may be appropriate and how to select the best system. Post-processing of the raw data can also be time-consuming. A systematic assessment of acoustic systems is required to identify the conditions under which they are likely to be effective for detection of sunken oil, and how the technology might be improved to increase their overall performance . This project was not able to perform more realistic tests at depths over 25 feet (8.5 feet at Ohmsett). For example, the trade-offs with depth, area coverage and data resolution need to be determined for each type of system.

4.2 Recovery

The key to enhancing future operations and sustaining the optimal recovery conditions is to determine the best combinations of delivery system type, delivery system movements, nozzle shapes and sizes, pump type and flow rates, and methods for properly coordinating the mechanics of a given recovery system. Efficient recovery of sunken oil that can be pumped requires:

- Reliable detection and mapping of the stationary oil.
- Delivery system appropriate for water depth and environmental conditions.
- Pumping system capable of handling the high viscosity oil at the located depth.
- Nozzle that maximizes oil intake while minimizing water and sediment intake.
- A visual system that can see enough of the surrounding area as well as the nozzle to ensure maximum exposure of the nozzle to oil.
- Decanting system to handle flow-rate of oil/water/sediment mixture.

4.2.1 Delivery System

In the past 10 years, underwater oil recovery techniques have advanced from predominantly surface-supplied diver vacuum or installed pumping systems in relatively shallow waters to the use of saturation diving systems and ROVs at greater depths (Elliott, 2005 and 2012).

One of the strong drivers for initiating this project was to find an effective pump delivery system to replace divers. Of the three systems suggested, only the ROV was able to be tested in the Ohmsett tank. The ROVs appear to be a reasonable delivery system for submerged oil recovery equipment, although refinements of the system designed by Alion are required for it to be fully successful.

The MPC manned submersible could not be tested at Ohmsett, but has been tested in the field by MPC and appears to be a successful way of delivering and running the recovery equipment. The OSBORS

Sub-dredge field test was discussed in Section 3.2.2. The excavator used at Ohmsett may be a useful delivery system for shallow water if the excavator is located on a solid platform or on land.

4.2.2 Targeting the Oil

In situ visibility is critical for any system to operate at peak design performance. In order to increase visibility and minimize the amount of water and sediments recovered, the suction nozzle of the pump must spend as much time as possible in contact with the oil. The best recovery rates at Ohmsett appeared to be when the pump operator could actually see the oil and target the nozzle accordingly. The clear water of the test tank permitted the operators to periodically check oil and/or system locations by looking over the side, which will probably not be an option for actual spills.

MPC and OSBORS would likely have more flexibility in the field with an expected full range of motion when the oil removal components are mounted on the submersible and crawler for the respective systems. The additional flexibility would allow the operator additional degrees of freedom to optimize nozzle orientation with respect to the oil. Even in ideal conditions, it’s possible that only 10-20 percent of the recovered material will be oil.

4.2.3 Pumping System

Two of the three pumps tested, MPC and OSBORS, were capable of pumping the highly viscous oil from a depth of 6-8 ft (1.8-2.4 m). These are very high capacity pumps that may be too powerful for anything other than very large spills. The limits of these pumps need to be identified. Oil properties, the amount of oil on the bottom and bottom type all need to be considered when selecting the optimal size of pump to minimize picking up water and silt and causing damage to the benthic community.

4.2.4 Additional Research

Additional research is needed in the following areas:

- Lab tests to determine range of oil that can be pumped for the various types of pumps and nozzle arrangements, including maximum water depth and hose length at which the pumping system is able to function.
- Cost/benefit analysis of the different types of pumps and delivery systems based on the location of the spill, including depth, bottom type, available logistical support, and environmental impact.
- Performance of pumping systems if using water injection, especially when oil flow is intermittent.
- The operational limits and optimal depths need to be determined for the various recovery delivery systems.

4.3 Decanting

Submerged oil recovery operations result in a significant, although manageable, amount of water and sediment being accumulated during the recovery process. Separation of the oil-water-sediment mixture collected during underwater oil recovery can become a limiting factor in the operation and overall throughput of the recovery system. The optimal decanting system was not tested and should be designed accordingly to handle these waste streams.

All of the vendors indicated that larger and possibly multiple collection tanks would be needed for a large spill. The size of the filter system (to extract silt and sand) varied from below 10 to 200 microns and this will also need to be adjusted for each spill. The use of multiple steps for separating oil is needed, especially

since any sand sticking to the oil may not separate during pumping operations. There was discussion about whether different bottom types, other than loose sand, would result in a similar volume of sediment. It is likely that because moving highly viscous oil sitting on the bottom requires high pump pressures, picking up the bottom material will most likely still be an issue. However, this needs to be tested in the open water environment for which these systems are designed.

Responders need to develop detailed guidance and/or computational tools for decanting systems based on the conditions of the spill. Such tools would explicitly take into account oil and sediment characteristics, as well as the volume flow rates desired for the recovery process. A possible area for further study is to determine whether the topography and sediment characteristics, along with those of the oil involved, can be characterized to permit a decanting system to be optimized for a particular situation at the beginning of the spill response, rather than by in situ modifying and adapting the system in response to observations that are made during the decanting system’s operation.

4.4 Other Issues

Each spill will be different and the FOSC will need to determine what techniques to use. Part B of this report provides some guidance for a FOSC responding to a spill of submerged oil, including a discussion of the net environmental benefit of recovery options. Additional guidelines are required for conducting a cost-benefit analysis during an actual spill. This has been done at previous spills by determining what a “recoverable amount” was, determining exactly how much it would cost to set up the equipment and deploy it, and then deciding if the recovery would be a benefit to people and the environment.

An assessment of these systems’ effects on wildlife and the bottom environment is also needed. Use of sonar or laser may be limited by the presence of marine mammals or other endangered species. State and local organizations also need to be consulted to verify the presence of any sensitive underwater or archeological sites.

PART B: SUNKEN OIL RESPONSE GUIDANCE

Part B is proposed language for FOSC guidance related to spill response for instances involving sunken oil on the subsurface floor. The intent is for the user to be able to lift this text out of the report and insert into the appropriate FOSC guidance documentation. It does not specifically address oil that is buried in the bottom or is contained in a sunken vessel.

1 RESPONSE GUIDANCE INTRODUCTION

In responding to any oil spill, it is essential that the Federal On Scene Coordinator (FOSC) knows the location, area coverage, and general physical condition of the oil to effectively deploy cleanup resources and protect environmentally sensitive areas.

For the purpose of this report and following the Coastal Response Research Center (CRRC) report (2007) , "submerged oil" describes any oil that is not floating at or near the surface. "Sunken oil" describes the accumulation of bulk oil on the seafloor. This report deals primarily with sunken oil.

Spills of submerged and sunken oil pose special challenges during all phases of an emergency response:

- Submerged oils are difficult to detect, track (while it is mobile), and map (when it becomes stationary).
- There are no proven containment methods for oil either suspended in the water column or deposited on the seafloor.
- Underwater recovery methods are complex, expensive, and inefficient. Submerged oil is often highly viscous, making it difficult to pump.
- Large volumes of water and/or sediment usually must be handled during recovery and disposal.
- Every submerged oil spill is a unique combination of conditions based on oil type and behavior, environmental setting, and physical processes.

APPENDIX B contains a list of submerged and sunken oil spills as well as descriptions of most of the sunken oil responses.

2 FATE OF SPILLED OIL AND OIL-BASED COMPOUNDS

When oils are initially released into the marine or aquatic environment, a number of processes can affect their behavior and fate. These include spreading, evaporation and oxidation, dispersion, dissolution, emulsification, biodegradation, and sedimentation. Chemical make-up, density, and viscosity of the oil will have a large impact on the resultant behavior of the spilled oil. Oil products with a specific gravity less than the surrounding seawater at the time of release will tend to form a surface slick. Oil products can make their way into the water column and seabed through a number of different mechanisms:

- The oil has an initial specific gravity greater than that of the water in which it is spilled.
- The specific gravity of the oil becomes greater than the water through the incorporation of sediments either as a result of being stranded on sand shorelines and washed back into near-shore waters or becoming entrained with high levels of suspended sand in breaking waves (either on the beach or offshore bars).

- The oil sinks following a fire that not only consumes the lighter components but also results in heavier pyrogenic products as a consequence of the high temperatures associated with the fire.
- The oil is injected directly into the seabed and sticks to it through mechanical adhesion.

Figure 11. shows a summary of the behavior of sunken or submerged oil based on the National Research Council (NRC) report (1999).

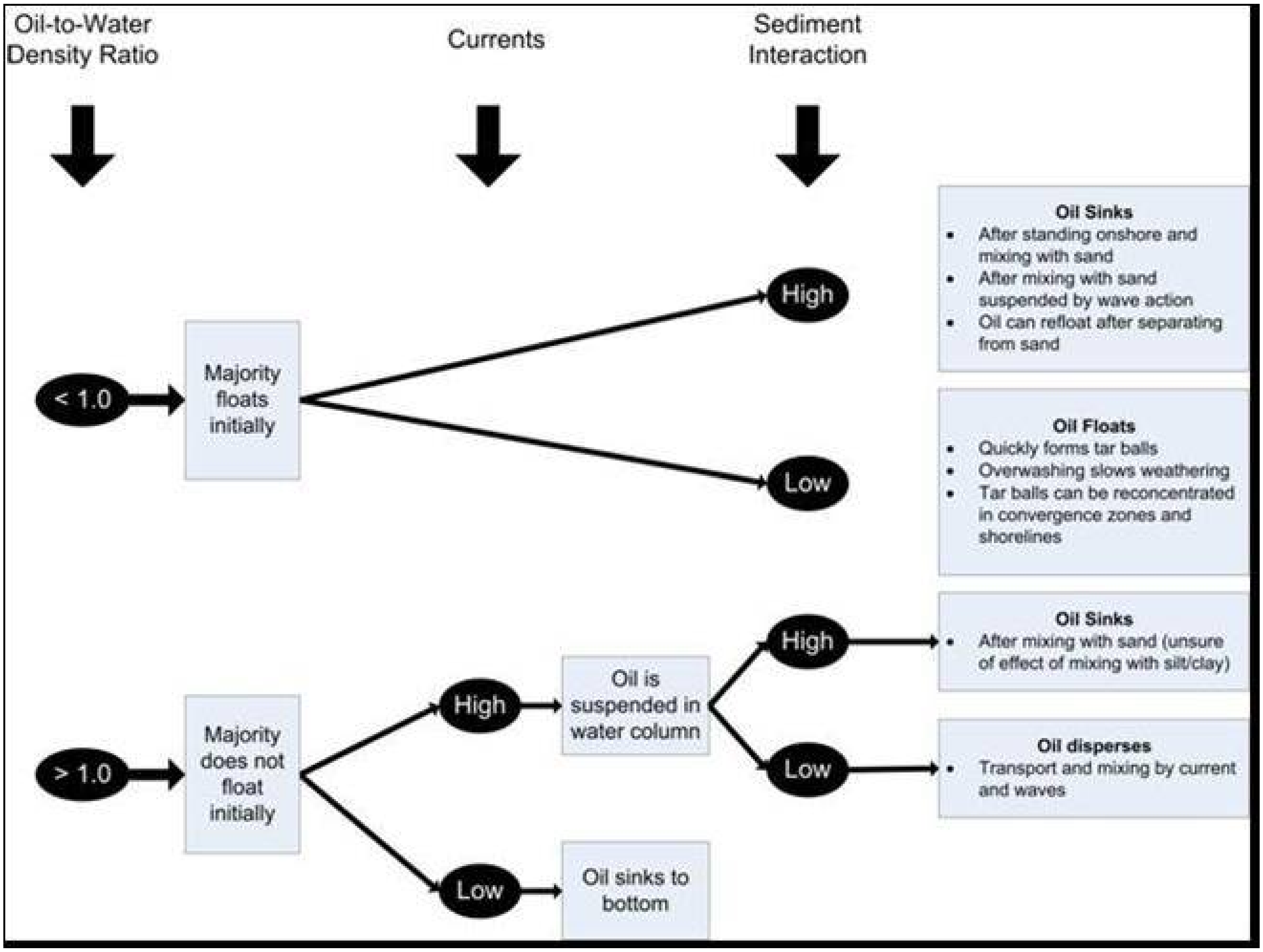


Figure 11. Summary of behavior of sunken or submerged oil.

Deposits of sunken oil are challenging to detect, track/map, and recover following an oil spill. Methods of detection and tracking/mapping, using existing techniques, are often inefficient and time consuming, involve labor intensive searches, and thus contribute to low recovery volumes for these kinds of spills.

Regardless of whether the spilled oil exists as a surface slick or as a deposit at the sediment/water interface, natural physical processes within the water column (surface waves, tidal currents, etc.), evaporation, and dissolution will cause the spilled oil-product to weather and properties to change over time. Submerged oils, however, weather at much slower rates than floating or stranded oil. Higher density oil deposits or tarballs on the seafloor are also affected by bottom current action and the incorporation of sediment grains into the oil matrix. Exposure to near-bottom currents of significant magnitude may result in transport of the

oil along the bottom by tidal, river, or storm wave currents and continued incorporation of native ambient sediment grains, as well as widespread dispersion from the original point of origin.

Submerged and sunken oil may move uncontrolled in the water column due to temperature changes, currents, gain or loss of sediments, and wave action. The result of a spill of heavy oil that sinks to the sea floor may therefore cause significant damage to the marine environment, recreational areas, sensitive industrial installations, and property such as boats and docks.

3 INITIAL ASSESSMENT

Once a spill involving sunken oil occurs, the FOSC must assess the situation and gather as much of the following information as possible to determine the best response methods.

1. Oil Spill Characteristics
   a. Type(s) of oil, including specific gravity and viscosity
   b. Volume
   c. Location or position of spill, including distance from port
   d. Areal extent of spill
   e. Time of spill to determine how long the oil may have been in the environment

2. Water Environment
   a. Depth
   b. Temperature
   c. Visibility
   d. Currents – surface and at depth
   e. Bottom type
   f. Topography
   g. Benthic –type and sensitivity
   h. Debris
   i. Waves

3. Other Environmental Considerations
   a. Weather conditions

4. Response Methods Available
   a. Detection – related to visibility/bottom type/debris
   b. Delivery method – related to topography/depth/visibility/environment
   c. Recovery – related to specific location and environmental conditions, characteristics of the oil, availability of equipment, and logistical support for the cleanup operation
   d. Decanting/polishing/storage – related to distance from port/debris/bottom type/weather effects

5. Logistics
   a. Equipment requirements
   b. Equipment availability
   c. Backup equipment/spares availability
   d. Availability of skilled/trained operators/workers
   e. Shore-side staging area
   f. Transit time to staging area and staging area to response site

4 DETECTING, TRACKING, AND MAPPING SUNKEN OIL

Locating and identifying heavy oil are problems of growing concern as the use of heavy oil and related slurry products becomes more prevalent. Despite the technological improvements that have been made in identifying oils spills through surface slick detection, detecting heavy oils with limited or no surface slick expression remains a challenge.

Measurements near the seabed become more challenging as the topographic relief of the bottom increases and the bottom surface becomes rougher. Fouling of instruments can also be a serious issue.

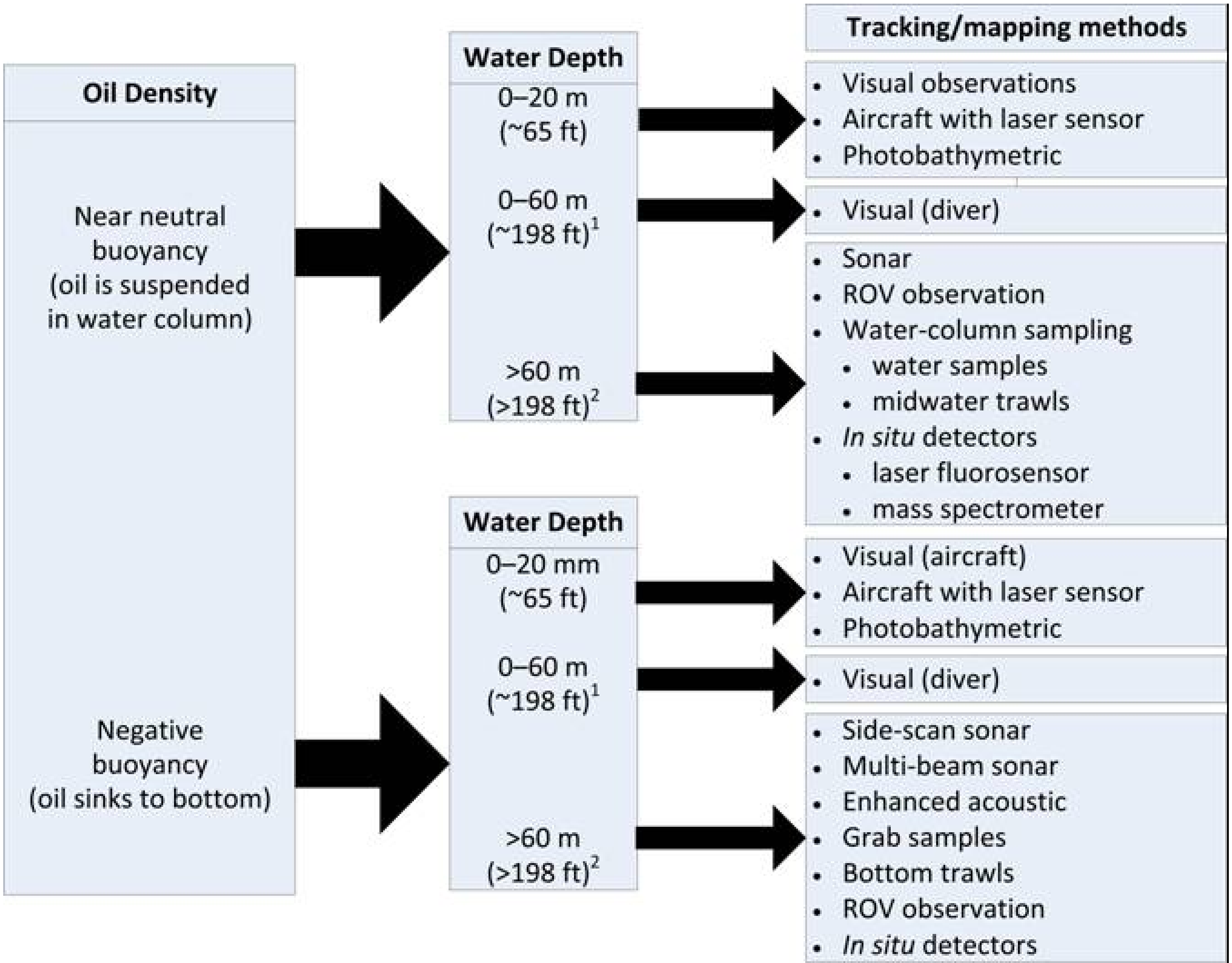
4.1 Methods

The appropriate method for detecting, tracking, and mapping oil deposited on the seabed depends on the water depth and clarity and environmental conditions. Figure 12 shows a traditional decision tree for methods to detect submerged and sunken oil (modified from the International Maritime Organization (IMO) Draft). The summary of detection methods is based principally on NRC, IMO, and various USCG documents. Other sensors are available for finding oil under the bottom although most have had limited use in past spills. During the Deepwater Horizon response, the detection of tarmats (oil mixed with sand) using sonar still had to be confirmed visually or by sampling and most anomalies identified came up negative (GCIMT, 2011). For a pipeline spill in Michigan in shallow water, probing techniques were used, but also usually had to be confirmed using sample grabs (Dollhopf and Durna, 2011).

Options for detecting and mapping oil deposited on the seabed include:

- Traditional/Manual
    - Visual/Video Observations
    - Photobathymetric (determining depths from aircraft)
    - Divers
    - Water Column and Bottom Sampling
    - Sorbent Drops and Snares
- Sensors
    - Sonar
        - Side-scan
        - Multi-beam
    - Fluorescence Spectroscopy
    - Laser Line Scan System

Table 1 summarizes issues associated with traditional options for mapping oil deposited on the seabed. Table 2 summarizes issues associated with sensor options for mapping oil deposited on the seabed.



[1]See Elliott, 2003 for more details regarding diving operations associated with pollution response.
[2]Maximum depth depends on specific sensor.

Figure 12. Detection and mapping decision tree (modified from IMO, 2012).

Table 1. Traditional options (columns) for mapping oil deposited on the seabed versus considerations (rows).

	Visual/Video Observations	Divers	Bottom Sampling	Sorbent Drops/Trawls/Nets
Description	Trained observers in aircraft or on vessels look for visual evidence of oil on the bottom. Includes underwater cameras on ROVs.	Divers (trained in diving in contaminated water) survey the sea floor either visually or with video cameras.	A sampling device (corer, grab sampler, sorbents attached to weights) is deployed to collect samples from the bottom for visual inspection.	Weighted sorbents, fish nets, or trawling gear are towed on the bottom for set distance then inspected for presence of oil.
Equipment Availability	Some forms use readily available equipment. Other options may be available from private area mapping companies, with specifications.	Underwater video cameras are readily available, but divers and diving gear for contaminated water operations may not be available locally.	Uses readily available equipment and supplies.	Readily available in commercial fishing areas.
Logistical Needs	Aircraft and vessels are readily available during spill response, but need to be equipped with instrumentation.	Depend on the level of diver protection required.	Requires boat, sampling equipment, GPS for station location.	Requires boat and operators for towing; may require multiple vessels to cover large areas; may require many replacements as gear becomes oiled.
Coverage Rate	High for aircraft; low for vessels and ROVs.	Low coverage, because of slow swimming rates, limited diving time, poor water quality.	Very low coverage; collecting discrete bottom samples is very slow; devices sample only a very small area.	Low coverage; have a small sweep area and they have to be pulled up frequently for inspection.
Data Turnaround	Quick turnaround for some methods. May be slow for photography.	Quick turnaround.	Relatively quick turnaround because visual analysis is used.	Results can be used immediately to revise search areas.
Probability of False Positives	High, due to poor water clarity, cloud shadows, seagrass beds, irregular bathymetry.	Low probability because divers can verify potential oil deposits.	Low probability, except in areas with high background oil contamination.	Low probability; oil staining should be readily differentiated from other fouling materials.
Operational Limitations	Requires good water clarity and light conditions; weather may restrict flights; can be used only during daylight hours.	Water depths of up to ~58m (190 ft) for surface-supplied air operations; minimum visibility of ~1m (3 ft); requires low water currents.	Sea conditions may restrict vessel operations.	Obstructions on the bottom can hang up gear; restricted to relatively shallow depths; sea conditions may restrict vessel operations.
Pros	Aircraft can cover large areas quickly using standard resources available at spills.	Accurate determination of oil on bottom; verbal and visual description of extent and thickness of oil and spatial variations.	Can be effective in small areas for rapid definition of a known patch of oil on the bottom; low tech option; has been proven effective for certain spills.	Can provide data on relative concentrations on the bottom per unit trawl area/time; can survey in grids for more representative areal coverage.
Cons	Only effective in areas with high water clarity; sediment cover will prevent detection over time; ground truthing required.	Slow; difficult to locate deposits without GPS; decontamination of diving gear can be costly/time consuming.	Samples a very small area, which may not be representative; too slow to be effective over large area; does not indicate quantity of oil on bottom.	Very slow; sorbents or nets can fail from excess accumulation of debris. Labor intensive.

Table 2. Sensor options (columns) for mapping oil deposited on the seabed versus considerations (rows).

	Side Scan Sonar	Multi-beam Sonar	Laser Fluorescence
Description	Sonar system that uses the differential density and sound speeds in oil and sediment to detect oil layers on the bottom; a fathometer records a single line under the sounder; side-scan sonar records a swath; output can be enhanced to increase detection.	Sonar system that measures relative water depths over a wide swath perpendicular to the towing vehicle's track.	A diode-pumped, solid-state laser is used for fluorescence excitation of the oil.
Equipment Availability	Requirements vary; often not available locally; need trained personnel.	Limited in some areas.	Only one system exists.
Logistical Needs	Requires boat on which equipment can be mounted; requires updated charts so that search area can be defined.	Requires boat on which equipment can be mounted and updated charts.	Easily mounted on delivery vehicle. Requires little to no maintenance.
Coverage Rate	Moderate/good spatial coverage.	Moderate/good spatial coverage.	Low spatial coverage. Can project to at least 12 m (40 feet) in clear water
Data Turnaround	Medium turnaround; data processing takes hours; preliminary data usually available next day; requires ground truthing.	Slow, may require ground truthing.	Data acquisition is in real time (<1 second). [EIC]
Probability of False Positives	High probability; identifies potential sites but all need ground truthing.	The Reson Sonar tested at Ohmsett had a false alarm rate of about 20 percent.	Almost no false positives.
Operational Limitations	Sea conditions must be relatively calm to minimize noise in the record.	Additional testing required.	The FP instrument housing has been tested up to a depth of ~40 m (130 ft) with no problem. Deeper operational depths will have to be tested.
Pros	Not affected by poor visibility; good visualization of large oil accumulations and other bottom features (e.g., debris piles, pipelines); complete systems can generate high-quality data with track lines, good locational accuracy.	Some systems can generate high-quality data with track lines; good locational accuracy; software detection algorithms can increase search efficiency.	Can use systems close to bottom; data output easy to interpret.
Cons	Once the oil spreads out, has reduced success at oil identification; slow turnaround (days) for useful product; less accuracy in muddy substrates; requires skilled operators.	Requires extensive ground truthing; requires skilled operators.	Of limited use in turbid waters.

4.2 Recommendations for Detection

Recent USCG Research and Development Center (RDC) efforts have determined it should now be possible to detect and map stationary oil on the sea floor and river beds under some conditions. The limits of the abilities of the sensors still need to be tested in real-world conditions, including depth of water, visibility, and bottom conditions.

The most direct and simplest methods, such as diver observations and direct sampling, are widely used, but they are labor intensive and slow. The deeper the water, the less viable these methods become. Advanced technologies, such as acoustic and laser techniques, require specialized equipment and highly skilled operators. The RDC recommends multi-beam sonars and laser fluorometers as best practice. However, detailed guidance for their use during actual responses needs to be developed as experience is gained.

Additional guidance includes:

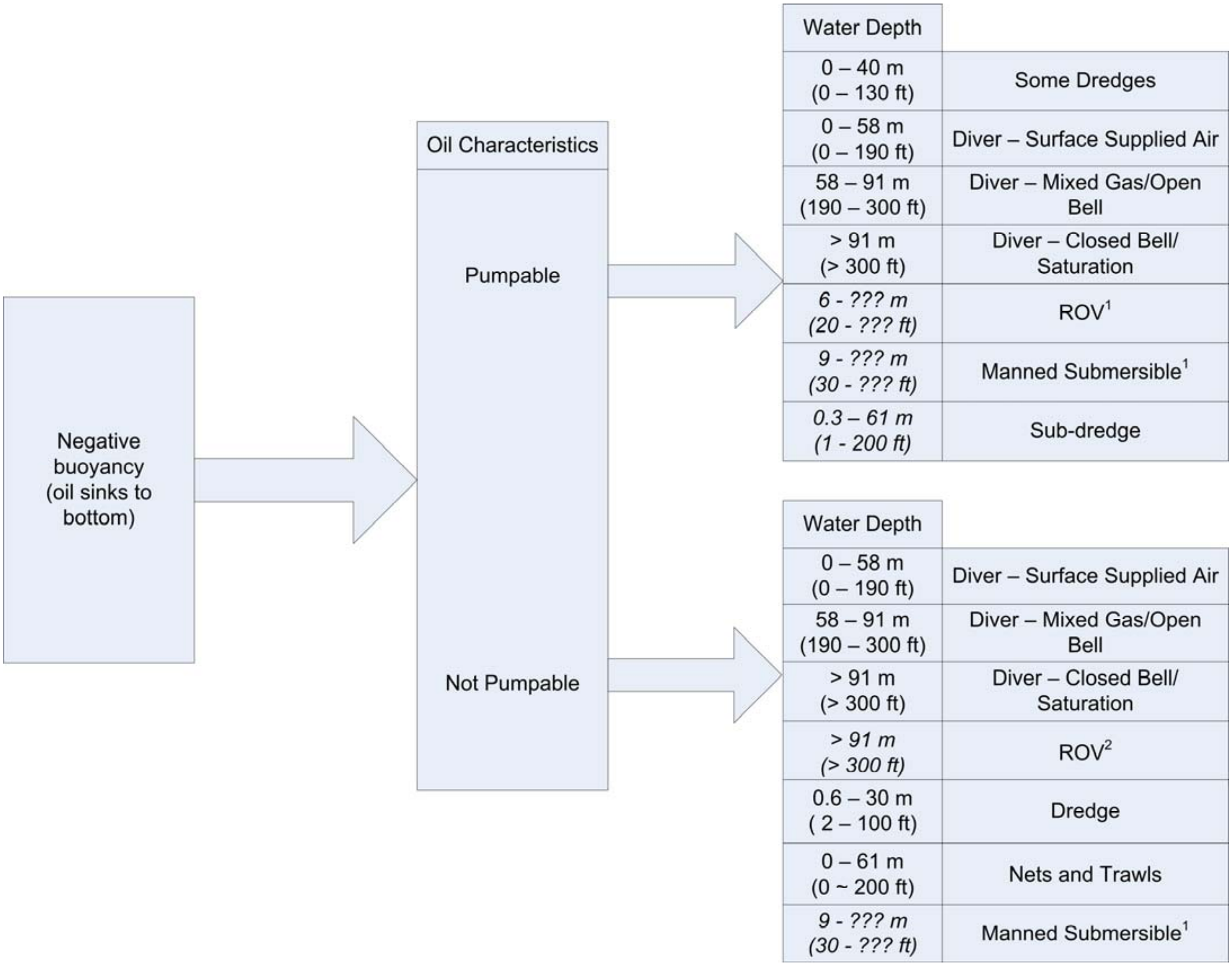
1. Determine amount of potentially destructive oil (oil that may contact or effect water inputs, sensitive areas, etc.) or recoverable oil. This helps to define the resolution of the detection method needed. Recoverable amount is a function of time to reach the oil (including transit and mooring), capability of cleanup technique, weather, and amount of decanting equipment and/or storage available.
2. Try most simple method first that addresses amount of oil being detected.
3. Use sophisticated methods for deeper and larger amounts of oil. Use models, if available, to determine search area and potential amount of oil that may be recovered.
4. Sonar can search a wide area but processing must be timely and of sufficient resolution. Have vendors determine resolution (i.e., the size of the patch of oil that can be detected), amount of time to search any area, and the amount of time to process the data.
5. Advanced software processing packages exist that can recognize patterns. These are very useful to determine where the oil is not located but still can produce false positives and additional sampling will most likely be needed.
6. Laser system operators also need to define the area covered, estimated patch size, and the time to process the data.
7. Utilize differential Global Positioning Systems (GPS) for finer search grids if available.
8. Minimize the amount of time between the detection and collection phases of the response.

5 SUNKEN OIL RECOVERY

The selection of the recovery method is highly dependent on:

- Specific location and environmental conditions during the spill.
- Characteristics of the oil and its state of weathering and interaction with sediments.
- Availability of equipment, and logistical support for the cleanup operation.
- Potential environmental impacts of implementing these methods, particularly in sensitive benthic habitats.

Figure 13 shows a decision tree for sunken oil recovery options (based on the one originally proposed by Castle et al., 1995). Options are based on whether the oil is pumpable or not and the depth of the water column. While divers can go deeper, unless there is a large amount of oil potentially being recovered, the recovery process may be too risky.



[1]Depth depends on pump capabilities.
[2]Depth depends on ROV capabilities.

Figure 13. Decision tree for recovery options for sunken oil.

The success of current methods varies greatly but is usually limited when the oil is widely distributed and/or the oil is mixed with sediments and water. In general, available methods are most successful when:

- Current speeds and wave conditions at the spill site are low.
- Water visibility is high.
- Oil is pumpable.
- The water is relatively shallow.
- The sunken oil is concentrated in natural collection areas.

While some cases of direct-sinking oil have occurred (e.g., *DBL 152*), in most instances even heavy oils do not sink unless exposed to sand or other particulates. This is usually a result of being washed in surf or onto beaches. If not collected on shore, the sand-laden oil may move back out to sea where it can wash along the bottom until a storm re-deposits it on the beach. Offshore recovery efforts for submerged oil tend to be labor intensive, dangerous, and ineffective. In those rare cases when they are carried out, it is generally in shallow waters near popular coastal areas. However, techniques are being developed that may make recovery of sunken oil in deeper water more feasible. The exact depth limitations of these techniques still need to be determined as experience is gained in different situations.

Table 3 summarizes issues associated with sunken oil recovery options for pumpable oil. Issues true for all pump delivery systems include:

- System includes pump and vacuum connected to oil-water separator.
- Viscous oils require special pumps and suction heads.
- Needs capacity for handling large volumes of materials during oil-water-solids separation, storage, and disposal.

Table 4 summarizes issues associated with sunken oil recovery options for oil that cannot be pumped.

Table 3. Sunken oil recovery options (columns) versus considerations (rows) – oil can be pumped.

	Diver-directed Pump and Vacuum Systems	Remotely Operated Vehicle (in water column)	Sub-dredge (bottom tracking ROV)	Manned Submersible
Description	Divers direct a suction hose connected to a pump/vacuum system.	ROVs are used to deliver a pumping system to the oil and direct its position during recovery.	Tracked seabed unit on which is mounted a pump and movable, controllable suction head.	Recovery device is mounted on a mini submarine.
Equipment Availability	Readily available equipment but needs modification to spill conditions, particularly pumping systems.	System must be selected for the application.	Specialized unit available from manufacturer. Required lead time unknown.	Specialized unit available from manufacturer. Required lead time unknown.
Logistical Needs	High, especially if recovery operations are not very close to shore. On-water systems will be very complicated and subject to weather, vessel traffic, and other safety issues. Requires experienced divers and support teams.	Stable VOO platform with sufficient deck space and equipment to store the submersible, operations module, and support equipment.	Stable vessel of opportunity (VOO) platform with sufficient deck space and equipment to store the dredge and support equipment.	Stable VOO platform with sufficient deck space and equipment to store the submersible and support equipment.
Operational Limitations	Water depths up to ~58m (190 ft) for surface-supplied air operations; water visibility of ~0.5m (1-2 ft) so divers can see the oil (see Elliott (2003) for additional considerations).	Water depth limited due to vehicle rating and length of tether, water visibility of 1-2 m (3-5 ft).	Depth: 0.30-60 m (1-200 ft). Not usable for some bottom types.	Wind 30 kts (45-kt gusts) Wave 0-2m (0-5ft) Current 0-2 kts Lightning <5miles Minimum depth of about 9m (30 ft)
Optimal Conditions	Sites adjacent to shore, requiring minimal on-water systems; liquid or semi-solid oil; thick oil deposits, good visibility; low currents.	Sufficient water depth to limit surface wave interference with depth control. Clear water.	Low benthic sensitivity to limit affects of driving over bottom. Oil located by surface methods.	Sufficient water depth to limit surface wave interference with depth control. Low current (<2 kts). Fair visibility.
Pros	Most experience is with this type of recovery; diver can be selective in recovering only oil and effective with scattered deposits. Even in low water visibility, divers can identify oil by feel or get feedback from top-side monitors of changes in oil recovery rates in effluents.	Increased visual access to the bottom topography and the contaminated bottom via remotely operated video; reduced cross contamination and contaminant dispersal; increased "on oil" recovery time – tethered vehicle does not have to be recovered to change out operators.	Increased visual access to the bottom topography and the contaminated bottom via remotely operated video; increased "on oil" recovery time – fast.	Reduced physical interaction with the contaminated bottom; increased visual access to bottom topography and areas of contamination; reduced cross contamination and contaminant dispersal; improved collection efficiency.
Cons	Very large manpower; problems with contaminated water diving and equipment decon; slow recovery rates; weather dependent operations.	Moderately high cost; trained/skilled operators required; eyes on site not as effective as manned submersible – less ability to adapt on site.	Moderately high cost; trained/ skilled operators required; bottom tracking submersible will have a greater impact on benthic and has a higher likelihood of contamination from oil.	Cost; reduced on oil recovery time due to returning to VOO to change out operators; trained/skilled operators required; amount of deck space required.

Table 4. Sunken oil recovery options (columns) versus considerations (rows) – oil cannot be pumped. (Modified from Castle et al., 1995)

	Manual Removal by Divers	Nets/Trawls	Dredging
Description	Divers pick up solid and semi-solid oil by hand or with nets on the bottom, placing it in bags or other containers.	Fish nets and trawls are dragged on the bottom to collect solidified oil.	Special purpose dredges, usually small and mobile, with ability for accurate vertical control. Uses land or barge-based systems for storage and separation of the large volumes of oil-water-solids.
Equipment Availability	Contaminated-water dive gear may not be locally available.	Nets and vessels readily available in areas with commercial fishing industry.	Varies; readily available in active port areas; takes days/week to mobilize complete systems.
Logistical Needs	Moderate; diving in contaminated water requires special gear and decon procedures; handling of oily wastes on water can be difficult.	Low; uses standard equipment, though nets will have to be replaced often because of fouling.	High, especially if recovery operations are not very close to shore, because of large volumes of materials handled. On-water systems will be very complicated and subject to weather, vessel traffic, and other safety issues.
Operational Limitations	Water depths up to ~58m (190 ft) for surface-supplied air operations; water visibility of ~0.5m (1-2 ft) so divers can see the oil; bad weather can shut down operations (see Elliott (2003) for additional considerations).	Water depths normally reached by bottom trawlers; obstructions on the bottom which will hang up nets; rough sea conditions; too shallow for boat operations.	Min/max water depths are a function of dredge type, usually 0.6-30m (2-100 ft); not in rocky substrates; bad weather can shut down operations.
Optimal Conditions	Shallow, protected areas where dive operations can be conducted safely; small amount of oil; scattered oil deposits.	Areas where bottom trawlers normally work; solidified oil.	Large volume of thick oil on the bottom; need for rapid removal before conditions change and oil is remobilized, buried by clean sediment, or will have larger environmental effects.
Pros	Divers can be very selective, removing only oil, minimizing the volume of recovered materials; most effective method for widely scattered oil deposits.	Uses available resources; low tech.	Rapid removal rates; can recover non-pumpable oil.
Cons	Large manpower and logistics requirements; problems with contaminated water diving and equipment decon; slow recovery rates; weather dependent operations.	Not effective for liquid or semi-solid oil; nets can quickly become clogged and fail; can become heavy and unmanageable if loaded with oil; could require many nets which are expensive.	Generates large volumes of water/solids for handling, treatment, disposal; large logistics requirements; could re-suspend oil/turbidity and affect other resources.

6 DECANTING

Submerged oil pumping operations utilize water as a carrier device to transport oil while performing recovery, a necessary function that results in the accumulation of a large amount of water in the storage tanks. Inefficiencies in targeting the pump nozzle to the oil may result in an additional volume of water. Depending upon the nature of the oil, the benthic environment, and the efficiency of the pump and its nozzle, a large load of sediment or sediment-loaded oil may be unavoidably collected. Separation of the oil-water-sediment mixture collected during underwater oil recovery can become a limiting factor in the operation and over-all throughput of the recovery system. The decanting system must be designed accordingly to handle these waste streams.

The wide range of oil types and environmental conditions that could be encountered during submerged oil recovery operations requires a strategy for assembling different types of decanting systems to suit different types of submerged oil spills, based on an inventory of components (tanks, heaters, pumps, filters) that could be drawn together using standard interfaces (compatible fittings, hoses, etc.).

Figure 14 shows the general components recommended for a decanting system. The attributes that must be considered for a decanting system intended especially for submerged oil recoveries are as follows:

- The ability to separate out sediment and other solids.
- The ability to separate oils of varying density and viscosity from either seawater or fresh water, including the ability to collect both the oil fraction that remains heavier than water, and the fraction that refloats during the process.
- The ability to configure the system appropriately for different types of recovered spill and on different recovery platforms.
- The ability to avoid or resist clogging due to suspended sediment or high-viscosity oil, or a combination of both, but without relying on uneconomically frequent or labor-intensive cleanouts or changes of strainers / filters; general ease of maintenance and low power requirements.
- Resistance to the chemical effects of different types and grades of recovered oil.
- The ability to operate satisfactorily under the anticipated motions of the recovery platform. Recovery platforms are nearly always platforms of opportunity and the range of ship motion is fairly broad even though the environment anticipated for recovery operations is usually modest compared with rough weather for a seagoing ship. Settling and decanting can be quite sensitive even to modest platform motions, and can then become a bottleneck in the over-all system throughput.
- Security against the possibility of becoming a secondary spill source.
- Safety of personnel, system reliability, and low costs for acquisition and operation are considered highly important design criteria.

In situ oil on the sea floor may be either intrinsically denser than water, or it may be on the bottom because it adheres to or becomes mixed with sediment. When disturbed or agitated, whether by the natural environment or the recovery process, some fraction of the oil may refloat, while some fraction may remain heavy enough to settle out. During the *Berman* spill, the oil sank at night but refloated as it was warmed by the sun. In any case, the difference in density between water and oil may be small, so that settling proceeds rather slowly. Logistics and costs are reduced if the material can be handled on land, compared with using barges for temporary storage and separation.

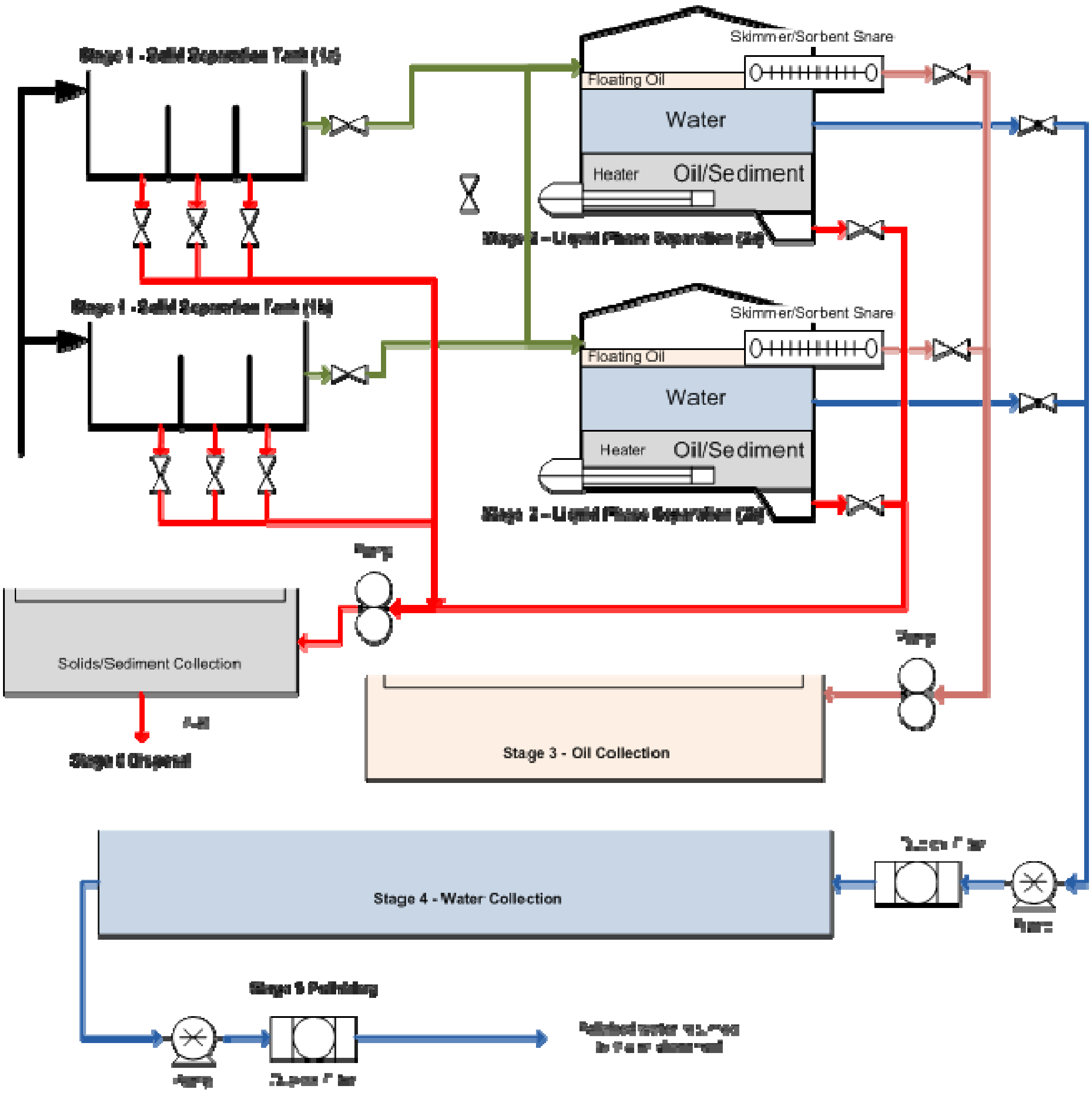


Figure 14. Recommended decanting system.

Specific stages in a decanting system include:

Stage 1 Solid separation: Baffles, filters, and/or gravity settling are used in this stage. The time required will depend on the nature of the solids. The liquid portion is pumped to another tank for Stage 2. Solids, which most likely are contaminated, will need to be removed from the bottom of the tank. Tank 1A may need to be replaced with tank 1B (and tank 1B put into service) for this to be accomplished. This operation may require the introduction of heavy machinery to aid in efficient solid waste management (i.e., the use of a crane with clam bucket or an excavator appropriately outfitted) as well as placement of appropriate secondary solid waste containers at the site.

Stage 2 Liquid phase separation: Oil is separated from water using aeration, heating, and/or gravity separation. In most cases some oil will sink and some will float.

Stage 3 Collection of oil: Floating oil can be collected from Stage 2 using skimmers and/or sorbent snares and pumped to or placed in tank 3. Sunken oil will need to be removed from the bottom of the tank. Multiple tanks may be needed for this to be accomplished.

Stage 4 Collection of water: Water (middle layer between floating and sunken oil) needs to be pumped into the Stage 4 Tank.

Stage 5 Polishing of water: Water can be polished using filters or oil absorbent systems and returned to the environment. Typical filtration systems applied to oil spill decanting operations include sand and carbon filtration units, specialized bag/chamber filtration methodologies, and some custom designed filter devices that fit on the end of discharge hoses. In each case the selection process for specifying the filter media should be based on compatibility with the type of oil that will be encountered. It is also important to ensure that the filter methodology selected allows for the required flow rate of the system as a whole, a decision factor that may require multiple banks of filters to ensure that a bottleneck condition does not occur at this final step in the process, resulting in shutting down operations to clear space in tanks ahead of the filtration process.

Stage 6 Disposal: Collection of oil, oiled debris, and decontaminated sand/sediments.

7 NET ENVIRONMENTAL BENEFIT ANALYSIS

7.1 Introduction

Nonfloating-oil spills pose a substantial threat to water-column and benthic resources, particularly where significant amounts of oil have accumulated on the seafloor. Sunken oils tend to weather slowly and thus can affect resources for long periods of time and at great distances from the release site. However, sunken oil recovery techniques have the potential to cause more damage than the original oiling. One of the other issues for submerged oils is the "How Clean is Clean" decision, which looks at the incremental environmental and socioeconomic benefit of continuing a cleanup vs. the typically increasing cost per unit of oil removed and seeks to define an economically reasonable cleanup endpoint. Consideration should be given to conducting a Net Environmental Benefit Analysis (NEBA) prior to recovery operations.

NEBA for oil spills on the surface has become an accepted and refined practice supported by protocols and information sources (National Oceanic and Atmospheric Administration (NOAA), 2001 and 2010). It is now generally clear when certain countermeasures such as dispersant application and in-situ burning are appropriate given the projected movement of oil, the marine species in the water column, the environmental sensitivity of nearby shorelines, and proximity of populated areas.

The NEBA concept clearly applies to spills of submerged and sunken oil as well, particularly if the oil has come to rest on the bottom so that a concerted cleanup effort is warranted. Certain bottom habitats are more ecologically valuable than others; certain cleanup techniques are more intrusive and potentially damaging than others. Consideration must also be given to the mobility of the oil and potential impact on resources in the surrounding area. However, unlike surface and shoreline cleanup situations, there is very little in the way of protocols and information sources to support NEBA for submerged and sunken oil. This is partially due to the relative infrequency of these spills and the small number of cases in which cleanup has been

undertaken and documented. However, even though the NEBA process for submerged and sunken oil is not as prescriptive and rigorous as for surface spills, there are NEBA concepts which should be considered. The following discussion addresses some of these concepts.

7.2 Environmental Sensitivity Considerations for Water Column and Bottom

Just as there are different shoreline types, each with different ecological values and degrees of difficulty in cleanup, so too are there different water column types and bottom types that should be considered when undertaking cleanup operations for submerged and sunken oil. Factors that should be considered include:

- Ecological sensitivity.
- Persistence of oil in the environment.
- Proximity to surface resources including shorelines, beaches and infrastructure, economically valuable marine resources.
- Presence of threatened and endangered species.
- Possibility of historic/archeological resources.

In addition, there are bottom safety hazards that must be considered including electrical cables, pipelines, unexploded ordinance and sites of previous contamination. Each of these considerations is discussed in some detail below:

- Ecological Sensitivity – Although each section of bottom will have unique characteristics, some generalizations can be made on the ecological sensitivity of bottom types similar to the classifications assigned to shoreline types. Bottom types will range from the most ecologically sensitive and important such as coral reefs, seagrass and eelgrass beds, and kelp forests to the less important such as rocky substrate, sand, and mud. Probably the least sensitive bottom types are sand and mud bottoms in areas that already suffer from pollution such as industrial areas. Note that the NOAA ESI maps will generally delineate sensitive bottom habitats that are in shallower water adjacent to the shoreline. The NOAA Scientific Support Coordinator (SSC) and state resource trustees (e.g., Department of Natural Resources (DNR) and Department of Environmental Protection (DEP)) can provide information on bottom resources. In coastal areas, local fishermen are often familiar with bottom substrate type and marine resources.

- Persistence of Oil on the Bottom – The persistence of oil on the bottom depends on the permeability/porosity of substrate, the oil's density (buoyancy), and the adhesion properties of the oil. Persistence is also a function of bottom turbulence and currents. Persistence can either warrant or preclude rapid cleanup actions. If the oil is in an ecologically sensitive area, the persistence of the oil warrants more timely removal action. If the oil is likely to remain in an area of little ecological significance, then removal actions can be more intrusive and pursued at a slower pace, unless leaving it in place allows for future transport into more ecologically sensitive areas.

- Proximity of Sensitive Resources – As with surface spills, it is important to consider the current location of the oil and environmental sensitivity, but also the sensitivity of locations where the oil might be transported. Such areas include ecologically sensitive shorelines (salt marshes and mangrove areas), recreational beaches, municipal water intakes, and valuable infrastructure.

- Threatened and Endangered Species – Threatened and endangered species that are located in the area under consideration are usually identified on the ESI maps. As most of the threatened and endangered species of concern in an oil spill are marine mammals and birds, they are not likely to be

directly disturbed by removal of oil from the bottom. However, they may be injured or disturbed by response vessels and equipment, and contaminated if oil is re-suspended in the water column.

- Historic/Archeological Resources – Archeological and historic resources that are known (which are generally on the shoreline) are identified on the ESI maps. However, there may be historic and archeological resources below the water which have not been located and charted, which may be uncovered and disturbed by cleanup operations. The State Historic Preservation Officer (SHPO) and local officials should be consulted before dredging or other intrusive cleanup operations are undertaken on the bottom in areas of historic interest, or if wrecks or other artifacts are encountered during the operation.
- Safety Hazards – Safety hazards such as electrical cables, underwater pipelines, and unexploded ordinance should be indicated on navigation charts. Port Authorities, the U.S. Army Corps of Engineers (USACE), and local utility companies can provide more detailed information on infrastructure on the bottom. Some areas of the bottom (e.g., Superfund sites) may have toxic contaminants present in the sediments which would best be left undisturbed. The U.S. Environmental Protection Agency (EPA) and state and local environmental agencies should be consulted regarding the presence of these sites.

7.3 Generic Impacts from Various Containment and Cleanup Methods

Just as with shoreline cleanup techniques, subsurface and bottom cleanup techniques and technologies have collateral environmental impacts that warrant consideration. NEBA weighs the positive environmental impacts of removing the oil from the environment against the impact of the cleanup techniques themselves. In general, the faster and more intrusive the cleanup technique, the greater the associated impact. The impact of generic techniques used to date is described below:

- Manual Removal by Divers – divers locate and remove smaller concentrations of oil using hand tools or sorbents. The technique is effective but slow and labor intensive. It is best used with limited quantities of oil in shallower water and where sensitive bottom resources are involved. Damage to the local environment is minimized as long as oil is accessible and visibility allows location of the oil patches or globs.
- Diver or ROV Directed Bottom Vacuuming/Pumping – Oil is removed from the bottom using vacuum heads/pumping devices that are directed by divers or ROVs operated from the surface. Oil is removed but significant quantities of water, bottom sediment, and marine organisms can be removed as well with the amount depending on the precision with which the intake nozzle is manipulated. The level of environmental impact increases with the amount of sediment and marine organisms disturbed and/or removed.
- Bottom Nets and Trawls – The damage associated with use of these devices to collect oil on or near the bottom can be serious as they will disrupt or destroy bottom habitat and are likely to capture organisms that are less mobile and cannot escape.
- Dredging – Mechanical dredging using dedicated vessels and equipment is the quickest and most thorough method of removing oil from the bottom, but also the most intrusive and environmentally damaging. It is typically used in removing large quantities of semi-solid petroleum products from bottom environments of limited ecological value (although it might be used selectively in a sensitive environment to quickly remove the oil before it is mobilized and spread to a wider area of equal or

greater sensitivity). The bottom habitat is severely disrupted or destroyed and bottom organisms are removed and presumably killed. Soluble contaminants in the bottom sediments may be remobilized in the water column and spread to adjacent areas.

- Capping – Capping involves covering the contaminated area with an impermeable layer of material to isolate it from the environment. It has been used as a remediation technique for contaminated sediments and dredge spoil in cases where removal is impractical or would only spread the contamination. If the submerged oil is confined to a specific area and stable, it might prove useful as a temporary measure until an effective cleanup operation can be staged and implemented.
- No Action – As with surface and shoreline cleanup operations, the "no action" alternative should always be considered, particularly when the impact of the oil appears minimal in relation to the habitat disruption and marine organism mortality associated with removal. As with shoreline cleanup, this leaves the removal of the oil to natural biodegradation on the bottom.

Generally less intrusive techniques (e.g. manual collection by divers and diver-directed vacuuming) are better suited to sensitive environments unless urgent removal is the overriding consideration. Table 5 illustrates this showing that the less intrusive methods (e.g. manual removal and diver-directed vacuuming) are more universally recommended for all habitat types, whereas the more intrusive methods (e.g. dredging and capping) are not recommended for all but the least sensitive bottom types. Some intrusive methods might be provisionally recommended in sensitive areas if the contaminated area is small and expeditious removal is deemed necessary.

However, it is important to recognize that bottom type and sensitivity may vary considerably within a given area. The extent of oiling and permeability of the substrate will vary as well. Moreover, these variations will not be as obvious as they might be for shorelines where the habitat type and level of contamination are visible from the surface and air. Selection and application of a single approach based on decision-tools such as Table 5 may not produce the desired results. The use of several methods with continuous monitoring by diver and ROV, as well as consultation with the NOAA SSC and state resource trustees, are more likely produce the optimum net environmental benefit.

Table 5. NEBA recommendations matrix.

	Manual Removal	Directed Vacuuming	Bottom Net/Trawl	Dredging	Capping
Coral Reef					
Sea Grass Beds					
Kelp Forest					
Rocky Bottom					
Sand					
Mud					
		Recommended			
		Provisional			
		Not Recommended			

7.4 NEBA Process for Sunken Oils

Table 6 shows some of the decision factors and tradeoffs involved in the NEBA process for sunken oils. As indicated earlier, the variety of situations encountered in such spills, the limited information on bottom configuration and habitat, and the lack of experience and information on the effectiveness and impacts of cleanup techniques preclude straightforward and prescriptive protocols for making quantitative net environmental benefit determinations. Field guides and decision matrices for such spills have yet to be developed. However, there are strategic decisions that can be defined and decision factors that can be identified. These strategic decisions include the speed with which the oil must be removed, the amount of damage to the environment that can be accepted with rapid removal, and the longer-term environmental impact that can be tolerated by delaying recovery or leaving the oil in the environment.

Table 6. Summary of NEBA decisions for sunken oil.

Decision	Factors Involved	Tradeoffs
Urgency of Cleanup - How quickly must the submerged/sunken oil be removed from the environment?	• amount of oil spilled, • possibility of re-suspension and transport, • sensitivity of the surrounding area.	More rapid but intrusive cleanup options such as vacuuming and dredging will likely disrupt and/or destroy the habitat and organisms in the immediate vicinity of the oil, but may prevent subsequent damage to adjacent habit and resources that may be even more sensitive.
Acceptable Impact for Short-Term Removal– What is the level of environmental impact that can be accepted in effectively and expeditiously removing the oil from the bottom?	• amount and type of oil involved (small amounts of heavy, semi-solid oil are easier to remove than large amounts of liquid, neutrally buoyant oil), • intrusiveness of the technique (e.g. selective removal of larger concentrations by divers vs. complete removal by dredging), • sensitivity of the environment (susceptibility to collateral damage by removal technique).	Often the tradeoff involves choosing the most expeditious and effective technique that the bottom habitat can tolerate. A coral reef may require manual removal by divers or careful diver-directed vacuuming. A mud bottom in and industrial port area may easily tolerate dredging.
Acceptable Impact of Delayed Removal or No Action – Is it more environmentally beneficial in the long run to employ a less damaging cleanup technique or simply leave the oil for natural biodegradation?	• amount of oil, • the persistence and toxicity of the oil in the environment, • the sensitivity of habitats and organisms that may be impacted by the oil over time, • long-term transport and fate of the oil is important • whether the habitat is likely to be repopulated by organisms from adjacent areas	The tradeoff here is balancing the damage prevented in the short-term by foregoing intrusive cleanup options against the longer-term impact of leaving the oil in the environment.

7.5 Information Resources for NEBA

Applicable laws related to coastal resources protection that may apply to the impact of cleanup operations for submerged and sunken oil include:

- National Environmental Policy Act (NEPA) – administered by the EPA. NEPA requires federal agencies to consider the environmental impacts of proposed actions as part of their planning and decision-making (http://www.epa.gov/compliance/nepa/).
- Endangered Species Act (ESA) – administered by the NOAA National Marine Fisheries Service (NMFS) (http://www.nmfs.noaa.gov/pr/laws/esa/). The ESA provides for the conservation of species that are endangered or threatened throughout all or a significant portion of their range, and the conservation of the ecosystems on which they depend.
- Marine Mammal Protection Act (MMPA) – administered by the NOAA NMFS (http://www.nmfs.noaa.gov/pr/laws/mmpa/). The MMPA prohibits, with certain exceptions, the "take" of marine mammals in U.S. waters and by U.S. citizens on the high seas, and the importation of marine mammals and marine mammal products into the U.S.
- Migratory Bird Treaty Act (MBTA) – administered by the U.S. Fish and Wildlife Service (FWS) (http://www.fws.gov/laws/lawsdigest/migtrea.html).
- Magnuson-Stevens Fishery Conservation and Management Act – Essential Fish Habitat (EFH) – administered by the NOAA NMFS (http://www.nmfs.noaa.gov/sfa/magact/mag1.html).
- Coastal Zone Management Act (CZMA) – administered by the U.S. EPA. The objective of the CZMA is to control nonpoint pollution sources that affect coastal water quality. (http://www.epa.gov/agriculture/lzma.html).
- National Historic Preservation Act (NHPA) – Section 106 – SHPO Consultation; USCG must consider the effects of an undertaking (action) on historic properties, consult the SHPO, and provide the opportunity for making comments to local governments, tribes, and the public (along with the Advisory Council on Historic Preservation (ACHP) when required). This must be done prior to making final decisions (http://www.achp.gov/nhpa.html).
- Archeological Resource Protection Act (ARPA) – administered by the National Park Service. The purpose of ARPA is to secure, for the present and future benefit of the American people, the protection of archaeological resources and sites which are on public lands and Indian lands, and to foster increased cooperation and exchange of information between governmental authorities, the professional archaeological community, and private individuals (http://www.nps.gov/archeology/tools/Laws/arpa.htm).

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APPENDIX A. PHASE 2 AND PHASE 3 TEST RESULTS

Table A-1. Summary of test results from Phases 2 and 3.

Specification	Alion	MPC (Phase 2 only)	OSBORS
1. Presence of heavy oil on the sea floor identified with 80% certainty	Partial test – successful result. Phase 3 was successful with oil surrogates.	Tested – successful result	Not tested
2. Oil location georeferenced to within 16 ft (5 m) in accuracy	Partial test – successful result. Phase 3 was successful.	Partial test – successful result	Not tested
3. Minimal dispersion of oil or bottom material into the water column	Partial test – successful result in Phase 2.	Partial test – successful result	Tested – successful result
4. Provides real time data/feedback	Tested – successful result in Phases 2 and 3.	Tested – successful result	Tested (video during recovery) – successful result
5. Provides recovery for all sea floor conditions	Partial test – successful result in Phase 2.	Partial test – successful result	Partial test – successful result
6. Operates in fresh and sea water conditions	Partial test – successful result	Partial test – successful result	Partial test – successful result
7. Operates in water depths of up to 200 ft (61 m)	Partial test to 25 ft in Phase 3 - successful.	Not tested	
8. Minimal maintenance requirements	Partial test in Phase 3 - successful.	Not tested	
9. Easy to operate and requires minimal training	Tested – successful result. Partial success in Phase 3.	Tested – successful result	Tested – successful result
10. Easily de-contaminated and durable	Tested – successful result	Tested – successful result	Tested – successful result
11. Equipment operation not adversely affected by exposure to oil	Tested – successful result	Tested – successful result	Tested – successful result
12. Operates in water currents at the surface of up to 1.5 kts	Tested – partially successful in Phase 2. Successful in Phase 3.	Not tested	
13. Deploys and operates in up to 5-ft (1.5 m) seas	Partial test to 3-4 ft seas in Phase 3 - successful.	Not tested	
14. Operable during the day and night	Tested – successful result	Tested – successful result	Partial test (day) – successful result
15. Sets up within 12 hours of arriving on site	Partial test – successful result in Phases 2 and 3.	Partial Test – successful result	Tested – successful result
16. Viscosity: Operates in the range of 2,000-100,000 cSt	Tested – partially successful	Tested – successful result	Tested – successful result
17. Includes a decanting system that can handle the heavy or refloating oil	Not tested	Tested – successful result	Tested – successful result
18. Process to complete "polishing" of the resultant water for disposal	Not tested	Tested – successful result	Tested – successful result
19. Minimal impacts to benthic resources	Tested – partially successful in Phase 2. Successful in Phase 3.	Tested – partially successful result	Tested – partially successful result

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APPENDIX B. SUNKEN OIL INCIDENTS AND CASE STUDIES

Table B-1 gives a summary of incidents of submerged and sunken oil spills. The following descriptions (bold font in the table) are from the best documented cases of oil that sunk to the bottom (sea, lake, or river). They clearly show that the scenarios are very different and that solutions from one incident are not necessarily applicable to the next. They also demonstrate an issue with the identification of sites where oil has accumulated and its continuing mobility. In addition, oil may show both floating and non-floating behaviors during an incident: some parts may submerge while others sink and in some cases oil may have initially submerged, later sunk, refloated, and then repeat the process over a number of cycles. These case studies also show how the techniques for detection, monitoring, and recovery of sunken oil have evolved.

T/V Torrey Canyon

The *Torrey Canyon* spill in March of 1967 was one of the first to have issues of sunken oil. Oil impacting on the coastline which had not been observed moving on the sea surface, or arrived some time after bulk cleanup had been completed, was attributed to submerged and sunken oil. This was supported by diver surveys which identified isolated areas of sunken oil. However, during the incident attempts were also made to deliberately sink oil as a response strategy (IMO, 2012).

SS Sansinena

In December 1976, the Tanker *SS Sansinena* exploded in Los Angeles while loading bunker fuel oil. This resulted in a large pool of sunken oil at the incident site, which was confirmed by diver surveys to have collected in depressions up to three meters deep. With a large quantity of oil in a known location recovery operations were initiated utilizing vacuum trucks and separation tanks installed on a barge. It was planned that divers would maneuver the suction heads but this proved difficult, particularly as the divers could not control the suction rate directly. The suction heads were replaced by those utilizing hydraulic pumps which allowed greater control. Using the new heads, the divers encountered oil and sediment issues which resulted in them directing the pumps by “feel.” Following this, special pumping units were designed, which incorporated a different type of hydraulic pump, and were intended to be used without diver guidance. The new technique was found to have limited applicability except for large pockets of pooled oil. In total, nearly 675,000 gallons (2,555 cubic meters (m^3)) of the sunken oil had been recovered to this point. Finally a suction head and pump device was designed on-site to address recovery of the remaining oil. By the time it was ready it was necessary to use divers to direct the unit as some of the oil pools had become silted over, making the oil difficult to locate. This evolution of recovery techniques during an incident is typical and makes the determination of the ideal recovery system difficult (IMO, 2012).

T/V Alvenus

On July 30, 1984, the United Kingdom *T/V Alvenus* grounded with catastrophic structural failure in the Calcasieu River Bar Channel south-southeast of Cameron, Louisiana. It spilled 2.7 million gallons (t) (9,000 metric tons) of two viscous Venezuelan crude oils (American Petroleum Institute (API) gravity 13.2 and 18), creating the largest oil spill from a ship ever encountered in the Gulf of Mexico. A large portion of the slick approached the shoreline, absorbed suspended solid particles, and sank in the nearshore surf zones at Galveston Island. The submerged oil was mixed with sand, and most of the oil was deposited onshore as tarballs over a two-week period, causing continual re-oiling of adjacent beaches. No effective method of collecting the oil in the submerged state was discovered. Cleanup crews had to wait until the oil beached itself, a process that took several weeks (Alejandro and Buri, 1987).

Table B-1. Summary of incidents of submerged and sunken oil spills.

Date	Spill Name	Location	Oil Name/API	Spill Behavior/Conditions: Heavier than Water/Sank	Floated, then Sank after Stranding	Floated, then Sank without Stranding	Subsea Release
1967	***T/V Torrey Canyon***	**off Cornwall, UK**	**Kuwait crude oil**		**X**		
1976	***SS Sansinena***	**Los Angeles, CA**	**Bunker C/ 7.9-8.8**	**X (salt)**			
1978	*T/V Amoco Cadiz*	Brittany coast	Crude		X		
1978	*T/V Eleni V*	England	Heavy fuel oil (HFO)/ 14.4-19			X	
1979	*T/V Gino*	Brittany coast	Carbon black oil	X (salt)			
1979	*Ixtoc I*	Gulf of Mexico	Heavy crude oil		X		X
1979	*T/V Kurdistan*	Cabot Strait, Newfoundland	Bunker C			X	
1979	Lake Winona	Minnesota	No. 6 fuel oil/ 12	X (fresh)			
1980	*Tanio*	France	No. 6 HFO				X
1982	*T/V Katina*	North Sea	HFO / 10.7			X	
1983	*T/V Hanon Jade*	Yosu, South Korea	Heavy Arabian Crude Oil	X (salt) (burn residue)			
1984	***T/V Alvenus***	**Louisiana**	**Merey, Pilon Crude/ 13.8, 17.3**		**X**		
1984	***T/V Mobiloil***	**Columbia River, OR**	**Industrial/resid-ual oil/ 5.5–11.3**	**X (fresh)**			
1986	***T/V Thuntank* 5**	**Sweden**	**No. 6 fuel oil**	**X (salt)**			
1988	***T/B MCN-5***	**Anacortes, WA**	**Heavy cycle gas oil/ -1.2**	**X (salt)**			
1988	*T/V ESSO Puerto Rico*	Mississippi River	Carbon black feedstock/ 2.0	X (fresh)			
1988	*T/B Nestucca*	Grays Harbor, WA	Bunker C/ No. 6 fuel oil			X	
1989	*T/V Presidente Rivera*	Delaware River, NJ	No. 6 fuel oil/ 17.4	X (fresh)			
1989	*T/V Aragon*	near Madeira	Maya crude oil			X	
1989	*T/V Scurry*	Lake Erie/Detroit River	Carbon black feedstock	X (fresh)			
1991	***M/V Haven***	**Genoa, Italy**	**Heavy Iranian Crude Oil**	**X (salt)**			
1991	*T/B Vista Bella*	Puerto Rico	No. 6 fuel oil/ 4.6-10		X		

Table B-1. Summary of incidents of submerged and sunken oil spills (Continued).

Date	Spill Name	Location	Oil Name/API	Spill Behavior/Conditions			
				Heavier than Water/Sank	Floated, then Sank after Stranding	Floated, then Sank without Stranding	Subsea Release
1993	*T/V Braer*	Garth's Ness. Shetland	Norwegian Gullfaks crude oil		X		
1993	***T/B Bouchard 155***	**Tampa Bay, FL**	**No. 6 fuel oil/ 10.5**		**X**	**X**	
1994	***T/B Morris J. Berman***	**Puerto Rico**	**No. 6 fuel oil/ 9.5**		**X**	**X**	
1995	*T/B Apex 3512*	Mississippi River	Slurry oil/ -0.6	X (fresh)			
1996	Detroit River	Detroit River	Coal tar oil/ -12.5	X (fresh)			
1996	*T/V Provence*	Piscataqua River, NH/ME	No. 6 fuel oil/ 6.2	X (fresh)			
1997	*T/V Evoikos*	Strait of Singapore	Heavy fuel oil			X	
1997	*M/V Kuroshima*	Summer Bay, AK	Bunker C / HFO No.6 / IFO 380		X (fresh)		
1997	*T/V Nakhodka*	Honshu, Japan	Medium Fuel Oil				X
1997	*T/V Nissos Amorgos*	Gulf of Venezuela	Bachaquero Crude		X		
1999	***T/V Erika***	**Bay of Biscay**	**Residual fuel oil**		**X**		
1999	*T/V Volgoneft 248*	Sea of Marmara, Turkey	HFO		X		
2000	Southeast Florida Mystery Spill	SE Florida	HFO		X		
2001	*T/V Baltic Carrier*	Baltic Sea, Denmark	Intermediate fuel oil (IFO) 380		X		
2002	*T/V Prestige*	France, Portugal, Spain	Russian M100		X		
2003	*M/V Fu Shan Hai*	Baltic Sea	IFO 380			X	
2004	***M/T Athos 1***	**Delaware River, PA**	**Bachaquero Crude/ 13.6**		**X**		
2004	***T/V Velopoula***	**Malaysia**	**Carbon Black Feedstock oil**	**X (salt)**			

Table B-1. Summary of incidents of submerged and sunken oil spills (Continued).

Date	Spill Name	Location	Oil Name/API	Spill Behavior/Conditions			
				Heavier than Water/Sank	Floated, then Sank after Stranding	Floated, then Sank without Stranding	Subsea Release
2005	***T/B DBL-152***	**Louisiana**	**Slurry oil/ 4.5**	**X (salt)**			
2005	*T/B EMC423*	Chicago, IL	Clarified slurry oil/ <10	X (fresh)			
2005	Lake Wabamun	Alberta, CN	No. 6 fuel oil/ 12			X	
2006	**Jieh Power Plant**	**Lebanon**	**IFO (burn residue)**	**X (salt)**			
2006	*T/B MM-53*	Ohio River, KY	64-22 asphalt	X (fresh)			
2008	*T/B DM-932*	Mississippi River	HFO No.6	X (fresh)			
2010	*Deepwater Horizon*	Gulf of Mexico	Light crude oil				X
2010	**Enbridge pipeline**	**Kalamazoo River, MI**	**Heavy crude oil (dilbit)**			**X (fresh)**	

T/V Mobiloil
In March 1984, the tanker *Mobiloil* spilled 168,000 gallons (636 m^3) of a Heavy Fuel Oil into the Columbia River. Due to the density of the river water (freshwater), the majority of the oil sank and moved along the riverbed, being transported by the river currents, often within one meter of the river bottom. The mid-water oil rose to the surface once the salinity of the water increased near the river mouth. This was the first U.S. spill where oil tracking techniques were focused on submerged and sunken oil. Tracking and location of the moving missing oil was rudimentary with weighted sorbents being used to attempt to fix (keep from moving downstream) oil on the river bed (IMO, 2012).

T/V Thuntank 5
In December 1986 the tanker grounded in very rough weather (winds up to 25 meters/second (m/s) (48 kts)) and released oil into the Baltic Sea. The oil that escaped could not be collected due to the heavy weather and no cleanup work was possible before the approaching winter due to the freezing of the sea. The oil was therefore spreading along a large area of the eastern coastline (Rymell, 2009). A considerable portion of the oil sank. Some of the oil that was pooled in the sheltered shallow water was recovered using a simple vacuum system. Hot water was fed from a work barge to nozzles fixed to a suction pipe held by a diver. The nozzles were set to project hot water up the pipe, creating suction and lubrication for the recovered oil. Rough separation of oil and water was carried out on the barge (Ansell et al., 2001).

T/B MCN-5
In January 1988, the tank barge *MCN-5* capsized and eventually sank in 120 feet (36 m) of water in Puget Sound near the Rosario Straits. The *MCN-5* carried heavy cycle gas oil. During the incident the oil was released and sank. Due to heavy currents and tidal changes in the area, initial response efforts focused on the sunken barge and its remaining cargo. Experiments were conducted to observe the oil behavior in the water column and predict its movement. As in the *Mobiloil* spill, weighted sorbent pads were used in an effort to map the extent of oil on the bed (IMO, 2012).

T/V ESSO Puerto Rico
In September, 1988, the *ESSO Puerto Rico* released 966,000 gallons (23,000 barrels) of carbon black feedstock while travelling along the Mississippi River toward the Gulf of Mexico. The carbon black rapidly emptied out of the cargo tank and into the river. The oil appeared to be churned into tiny globules and droplets by the action of the vessel's propwash. The oil quickly dissipated with the river currents. Again weighted sorbent pads were used in an attempt to map and fix oil locations. Except for a 10 barrel pool of oil directly below the vessels final anchorage point, only small traces of material were found and these were limited to deep locations along the riverbed (Burns, et al., 1995).

M/V Haven
The Cypriot tanker *Haven* caught fire and suffered a series of explosions on 11 April 1991, while at anchor seven miles off the coast of Genoa, Italy. The vessel was carrying approximately 3.8 million gallons (144,000 tonnes) of heavy Iranian crude oil. The initial explosions blew the deck off the central cargo tanks and split the ship in two. One part sank rapidly while the remainder of the ship and cargo burned fiercely for about 70 hours and then the vessel sank. Some of the unburned oil that was spilled into the sea naturally dispersed, a small amount was recovered at sea and some came ashore. The partially burnt oil was said to have sunk in the form of 'bitumen.' The cleanup included an unprecedented activity involving the cleanup of oiled subtidal sediment by divers from the low-tide line to 10 m (33 ft) depth. Near seagrass beds, divers manually picked oil-sand globules from the sea bottom. As a result of 1991 findings of residual oil in the deep-sea sediments of the Ligurian Sea, two deep-sea trawl surveys (presumably using fishing nets) were

conducted in the summer of 1992 to determine the presence and quantities of residual oil on the seafloor. Although highly patchy, residual oil from the M/C *Haven* was distributed over approximately 140 square kilometers (km^2) (34,600 acres) of seafloor (Martinelli et al., 1995).

T/B Bouchard 155

In August 1993, three vessels collided at the entrance to Tampa Bay, releasing an estimated 325,000 gallons (1,230 m^3) of No. 6 fuel oil. The oil weathered on the water surface for nearly 5 days before it came ashore during a storm. Surface oil and shoreline oiling were successfully removed; however, thick mats of sunken oil were found in nearshore subtidal habitats. In several areas, the sunken oil was removed using vacuum transfer units mounted on barges. Diver and area surveys found numerous areas of mobile tarballs, pancakes and three mats of sunken oil ranging in size from 150-200 ft (46-61 m) long, 10-20 ft (3-6.1 m) wide, and up to two inches (0.05 m) thick. The mats may have picked up sediments in the water column or after being stranded onshore. The sunken oil remained on the bottom and had the consistency similar to peanut butter. Attempts to remove the sunken oil included various vacuum-pumping strategies, which failed due to the viscous nature of the oil. After further careful study and evaluation, it was determined that manual removal by divers was the most feasible option for certain areas. However, the offshore mats were not removed, and oil continued to wash ashore for at least six months following the spill and was removed by conventional beach cleaning (IMO, 2012).

T/B Morris J. Berman

In January 1994, the *Morris J. Berman* barge grounded off Puerto Rico releasing a group V fuel oil. Although much of the oil floated, extensive quantities submerged and sank and were found in both offshore areas and in sheltered bays. Identification was aided by the affected areas having clear and shallow waters. The submerged oil did not emulsify and remained fluid enough to flow with a consistency described as similar to maple syrup. Over time the oil became more viscous and mixed with sediments in some areas. Some oil was observed to refloat every afternoon as a result of increased wind generated currents and the heating of the oil and water by the sun. This mobile sunken oil complicated the cleanup response. Three different methods were used to recover the submerged oil: diver-directed vacuuming of the more liquid oil; manual pickup by divers for the more viscous patches; and dredging. The diver-directed strategy was effective but slow due to the need to respond to moving targets. Dredging was finally used to recover the remaining submerged oil. This resulted in increased amounts of sediment being recovered but eliminated the ongoing problem (Burns et al., 1995).

T/V Erika

On 12 December 1999, the tanker *Erika* spilled a very high density, persistent HFO that impacted over 400 km (250 miles) of France's West Brittany coastline resulting in a protracted period of shoreline cleanup. One of the sites oiled by the HFO was Pen Bron, located seaward of the Croisic salt marshes. This large and very environmentally sensitive area with extensive salt pans and bivalve production was polluted by a significant spill of sunken oil buried in the sediment. In view of the risk to local resources and amenities, operations were undertaken to remedy the sunken oil spill: the pollution was mapped and cleanup techniques studied to define the optimum technique for removing the oil that sank and was buried in an area subject to strong tidal currents. Site restoration was conducted in two stages:

1. Sediment in the most polluted area (700 square meters (m^2) or 837 square yards (yd^2)) was mobilized by a mechanical shovel dredge mounted on a barge and the sediment was sent to a refinery to be disposed of along with waste from other locations.

2. Sediment from the surrounding area (10,000 m^2 or 12,000 yd^2) was removed by a pump dredger: pumping the sediment-oil-water mixture ashore to a lagoon where the oil was removed from the sediment by floatation and skimmed while the water was filtered before being released. The residual oil concentration in the sand was monitored by chemical analysis to decide on how to dispose of it best: replacing it on site or treating it as a specific waste.

This operation involved over 1.46 million gallons (5,500 tonnes) of sediment. Environmental impact was minimized as 85 percent of the sediment was reinstated safely on site, thus avoiding the risk of shoreline erosion which could have happened in the event of excessive sediment removal (Le Guerroue et al., 2003).

T/V Volgoneft 248

During a storm in December 1999 the Russian tanker *Volgoneft 248* broke in two in the Sea of Marmara off Istanbul, Turkey and spilled 418,170 gallons (1,578 tons) of HFO. Most of the oil came ashore, and was subsequently cleaned up manually, while the remaining oil sank in shallow water. The sunken oil caused re-contamination of cleaned shorelines during storms and a decision was made to try and recover oil from the seabed. Manual recovery by divers was used in preference to dredging to minimize damage to the seabed. The recovery included using a novel method for a “no cure – no pay” contract to manage the operation. The contractor was paid an agreed rate for the amount of pure oil collected. This approach proved successful and resulted in maximizing the recovery of sunken oil while discouraging the collection of material other than oil. The commercial incentive created in this type of contract may also help to resolve the problem of determining the appropriate cut-off for the collection of widely scattered pockets of sunken oil (Moller, 2002).

MT Velopoula

In July 2004, as a result of a flexible hose rupture at an underwater manifold, the *MT Velopoula* lost an estimated 15900 gallons (60 tonnes) of HFO in Port Dickson, Malaysia. Diver operations were complemented by the use of a crane operated 8” internal diameter high capacity air lift system with annular air injection, a large diameter delivery hose, and a ‘hood’ to increase the width of the sweeping swathe. Strong subsea currents moved or buried significant quantities of oil, prior to the receipt of the interpretation results of a sonar side scan survey carried out to determine probable locations of oil (IMO, 2012).

M/T Athos 1

On 26 November 2004, the *M/T Athos 1* struck several submerged objects while preparing to dock at the CITGO refinery in Paulsboro, NJ, resulting in two holes in the No. 7 port and center tanks. It was carrying approximately 13 million gallons (49,000 m^3) of Bachaquero Venezuelan crude oil, a heavy crude oil that is heated during transport. The final estimate of 265,000 gallons (1,000 m^3) released was announced in January 2005. Although the oil initially floated, there was concern that some of the heavy oil would mix with sediment and not float. Pooled oil was reported on the bottom at the collision site by divers conducting surveys for the submerged objects that holed the vessel. Shoreline assessment teams reported that oil stranded on sandy intertidal areas on Tinicum Island did not re-float with the rising tide. A few utility and industrial water intakes along the river close to the spill site reported oil in their water intakes that were drawing water from below the surface to depths of up to 6 m (20 ft) deep, though none reported shut downs. A special team was assigned to assess the extent and degree of submerged oil and develop recovery options.

Based on the available observations, it appeared that there were potentially two types of submerged oil: 1.) pooled oil that had accumulated in depressions and was not readily mobilized by normal riverine and tidal currents; and 2.) mobile oil that was negatively buoyant and subject to transport by riverine and tidal currents. Nearly 100 snare samplers were eventually deployed to track the spread of the mobile submerged

oil. The Vessel-Submerged Oil Recovery System (V-SORS) was developed to both search for and recover the mobile submerged oil (Figure B-1). The amount of oil recovered was very low, so the V-SORS became more of an assessment tool.

Figure B-1. The Vessel-Submerged Oil Recovery System (V-SORS).

There were some problems with both the snare samplers and V-SORS. Many of the snare samplers were lost because of strong currents, rough seas, or vandalism, and rough weather led to variable inspection periods. Existing samplers in areas with strong currents were replaced with heavier anchors, higher visibility buoys, and more secure attachment methods. The snare sampling effort was reduced in scope by mid-December because of its costs, since the risks to water intakes were assumed to be reduced by this time. Once the V-SORS devices were no longer being towed and the snare samplers were removed from the water, the Unified Command requested a cost-effective way to monitor the amount of submerged oil in the Delaware River. An industrial water intake consortium was developed to fulfill this purpose. Water quality professionals at facilities along the Delaware River were asked to visually monitor their intakes for oil, tarballs, and sheen and report the results to the Environmental Unit. The specific monitoring technique was determined by the participating facility.

Side-scan sonar – This technology was attempted early in the spill to detect oil that was pooled on the bottom because the systems were already being used to search for the submerged objects that holed the tank. Furthermore, it would provide complete coverage of potential oil deposits very quickly. Because the data were being collected as part of the investigation of the cause of the spill, the response teams were not allowed to actually view the output. However, survey specialists from NOAA and the Navy Supervisor of Salvage did review the data and reported that it could not be used to identify pooled oil. It was successful in identifying the areal dimensions of the trench where the pooled oil was found and recovered.

Diver-directed pumping – The diver-pumping operations were successful in that most of the pooled oil was recovered. An estimated 900 gallons (3.4 m^3) were recovered in five dives over three days' effort. The advantages of using divers were that the pooled oil was in one location, so the recovery was efficient (did not have to repeatedly re-position the barges, etc.). Problems with the pumping systems were resolved

quickly. The decanting system was not overwhelmed because of the relatively small volumes of oil/water/sediment handled. (Michel, 2006)

Lake Wabamun

On August 3, 2005, forty-three cars of a westbound Canadian National Railways freight train derailed on the shore of Lake Wabamun, just west of Alberta's capital city of Edmonton, spilling about 198,000 gallons (750 m^3) of Bunker C and 19,800 gallons (75 m^3) of a pole-treating agent on the lakeshore. The spilled materials quickly flowed into the lake, forming a slick that spread rapidly along the north shore of the lake, oiling more than 12 km (7.5 miles) of shoreline. Because of its density close to that of freshwater, and also after picking up sediments, a part of the spilled oil sunk on the bottom of the lake. Sunken oil eventually re-floated in the form of small tar-balls, sometimes coalescing then stranding on the shores. It was clear that some of the Bunker C had settled to the bottom, but its exact location was difficult to determine. Sorbent pads on long poles were used to probe the bottom, but these were ineffective since the Bunker C had formed a skin and did not adhere to the sorbent. Video cameras were tried but the dispersed nature of the oil meant that this was not successful except in some shallow water situations (Goodman, 2006). Teams used underwater viewing tubes from small boats and kayaks to search for oil on the bottom near shallow wetlands (Figure B-2). Standard terminology, photography, and validation sampling are needed for this method to be of value. The success of removing the oil from the lake bottom was limited.

Figure B-2. Visual survey at the Lake Wabanum spill.
(Photo credit: Merv Fingas, Pat Lambert, Bruce Hollebone, Khrishna, Deana Cymbaluk).

***DBL-152* Spill Incident**

Shortly before midnight on 10 November 2005, the Tug *Rebel* and Integrated Tank Barge *DBL-152* struck a submerged oil platform that had been damaged by Hurricane Rita about 55 km (34 miles) offshore Cameron, LA. The tug released the barge about 5 km (3.1 miles) from the platform, once a list in the barge was noticed. The barge drifted for about 15 km (9.3 miles) until she grounded. Twelve days later, the barge capsized. The *DBL-152* was carrying a heavy refined oil, called a slurry oil, with an API gravity of about 4. The methods by which the oil was blended turned out to be very important to understanding the behavior of the spilled oil.

Eventually, it was determined that 2.7 million gallons (10,200 m^3) of oil were released from the *DBL-152*. The response to this major spill of nonfloating oil posed many challenges to the response team, including a work area 55 km (34 miles) offshore, limited response and salvage resources because of the recent hurricanes, many down days due to weather, submerged oil on the bottom that was sporadically re-mobilized by storm events, and pipeline safety issues. A wide range of techniques for tracking, containing, and recovering the submerged oil were discussed and many were used.

The response team developed a plan to use V-SORS to search for the submerged oil lost along the vessel track after the impact site. As these surveys were being done, the vessel owner mobilized divers and a side-scan sonar system to look for debris fields and submerged oil. The side-scan sonar data showed a trench or scour extending from the impact site for about 5.5 km (3.4 miles) to the east, ending when the barge slowed and the debris pinned on the front of the barge fell off, forming a debris field. Divers found, videotaped, and sampled the oil that filled the entire length of the scour trench.

The V-SORS survey plan was re-designed to look for oil outside of the trench. By 24 November, it was concluded that there was little oil outside the trench. The response team felt that they had a handle on the oil in the trench and started plans for recovery of this submerged oil by a diver-directed pumping system. Submerged oil assessment efforts were then focused on the grounding site where the bulk of the oil had been released. An underwater video camera on a tether using visible light recorders was brought in to increase the areal coverage of visual surveys. The divers always videotaped their surveys, and the video was very useful in understanding the nature and behavior of the submerged oil.

By early January, the emphasis was on identification of recoverable oil using the underwater videocamera and monitoring of the potential spread using the snare sentinels. Side-scan sonar, brought back to identify debris, was also used to identify potential oil targets that were verified by underwater video camera.

From USCG FOSC Memorandum associated with *DBL-152* (found in Michel 2006): Termination of operation will result from a Unified Command decision based on stakeholder consensus and technical input, coordinated by the Environmental Unit. Typically, this recommendation is a function of trade-offs between the diminishing returns of continued recovery efforts, the vulnerability of the key natural, economic and cultural resources and the specific threat posed by the contaminant. It is a risk-based decision. In the case of the *DBL-152*, as the operational constraints posed by oil recovery increase, the command will begin considering such issues as pathway of exposure and likelihood of injury to the resources. This will include an assessment of oil toxicity, oil characterization (particle size), oil distribution on the ocean floor, and future trends regarding these factors weighed against the marginal cost of continuing recovery efforts.

The lessons learned from the *M/T Athos I* spill were applied at the *DBL-152* oil recovery (e.g., pump type, housing to avoid jams). There were three main problems with oil recovery: 1.) finding enough oil for efficient operations; 2.) only being able to work for 1-3 days between storms; and 3.) decanting. A new underwater video camera was brought in to identify sites with enough recoverable oil, with a threshold eventually set at least 500 barrels (the amount of oil that could be recovered in a 24-hour period) (Michel, 2006).

Note: Older versions of side-scan such as that used in the *DBL-152* response relied on a person to do the entire evaluation. The current versions use better processing to reduce the time and make a better output for interpretation.

Enbridge pipeline
On 26 July 2010, Enbridge reported that approximately 819,000 gallons (19,500 barrels) of oil had been released from its ruptured oil pipeline near Marshall, Michigan to Talmadge Creek and the Kalamazoo River at a point approximately 80 miles (129 km) upstream from Lake Michigan. Submerged oil was assessed and recovered at over 25 locations. Submerged oil recovery actions were performed using both conventional and improvised techniques. The least invasive recovery method consisted of sediment flushing (using river water), sediment raking, and/or aeration to liberate the submerged oil and float it to the surface for subsequent recovery via absorbents or vacuuming. The second primary method of submerged oil recovery consisted of sediment dredging to remove 5,500 cubic yards (4,200 m^3) of oil-containing sediment from the Kalamazoo River immediately upstream of Ceresco Dam (approximately 5.75 miles (9.2 km) downstream of the release). During the dredging operations, over 14 million gallons (53,000 m^3) of water were removed from the Kalamazoo River, treated and returned back to the river, under a National Pollutant Discharge Elimination System (NPDES) permit issued by the Michigan DNR. A Science Advisory Team (SAT) was established to provide recommendations to the Unified Command (UC) regarding various response methods and objectives. The SAT was comprised of environmental representatives from federal, state, and local stakeholder agencies and had the primary mission of making recommendations to the UC and to the FOSC to help guide oil recovery in a manner least damaging to the environment (Dollhopf and Durno, 2011).

- National Resource Trustees Consultation - Concurrent with containment and recovery actions, close consultation with national resource trustees ensured that any adverse effects were properly documented. The trustees also provided valuable ecological expertise for decision-making when evaluating response actions.
- Native American Tribal Considerations - In early 2011, pursuant to EPA's request under the National Historic Preservation Act (NHPA), Enbridge submitted to EPA a study of the impacted waterways and adjacent lands which identified and evaluated any cultural, historic, or archeological sites, within the response areas. EPA is currently reviewing the report and continuing to consult with Tribal Historic Preservation Officers and the Michigan Historic Preservation Offices to ensure that any historical or archaeological sites are being identified and appropriately protected during the oil spill response actions.
- Public Health, Drinking Water and Hydrogeological Study - Protection of the public health was a primary objective during the entire response. An extensive air monitoring and sampling program was implemented with thousands of air monitoring data points and samples collected. Air monitoring was performed by both EPA and Enbridge contractors using real-time field instruments measuring volatile organic compounds (VOCs), benzene, lower explosive limit, and hydrogen sulfide. Air samples were also collected in Summa canisters and Tedlar bags for analysis of benzene and other VOCs by a mobile and/or fixed laboratory.

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APPENDIX C. USCG INTERNAL REFERENCES

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